THE MECHANICS OF ELECTRICITY

CORDEIRO

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BY

F. J. B. CORDEIRO

AUTHOR OF
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PREFACE

When asked what electricity is, physicists a few years ago would reply, "We do not know," and the inquirer was made to feel that he had asked a foolish question. To Maxwell, electricity itself seems to have been rather an abstraction, and he occupied himself chiefly with its effects, or the strains it produces in dielectrics. To the ultra-Maxwellians who declare that "there is no such thing as electricity," it is a disembodied spirit, not necessarily connected with matter except in so far as this is necessary to render its effects observable.

The general consensus of opinion at present is that electricity is *something*. Lodge writes, "Electricity may possibly be a form of matter—it is not a form of energy. We have nowhere asserted that electricity and the ether are identical. If they are, we are bound to admit that the ether, though fluid in the sense of enabling masses to move freely through it, has a certain amount of rigidity for enormously rapid and minute oscillatory disturbances. Is the ether electricity then? I do not say so, neither do I think that in that coarse statement lies the truth; but that they are connected there can be no doubt."

Clausius surmised that electricity might be the ether, and if we may judge from certain passages the surmise amounted to a belief. This belief was, of course, not based upon any direct proof, for that is hardly possible, but was rather of the nature of an intuition. He seems to have been alone in this opinion.

The object of this book is to show that electricity and the ether are identical. The ether is electricity and electricity is the ether. It has been sought, through the cumulative and corroborative evidence of the phenomena to raise a presumption that amounts almost to a certainty.

THE ETHER

Electricity not many years ago was classed as a force of nature, of which there were a number of different kinds, separate and distinct. These different natural forces were given categorically as mechanical, electrical, gravitational, magnetic, vital, cohesional, chemical, etc., and, as the conception of force is intimately connected with that of energy or work, there were as many different kinds of energy. Heat was considered still another form of energy, and light still another.

Eventually it was recognized that some, at least, of these forms of energy were mutually convertible, and the doctrine of the conservation of energy led to the view that energy was a single entity, though capable of manifestation under a number of different forms. The next step was that force under all circumstances was a single entity—essentially the same under whatsoever guise it might present itself. It was recognized that in the universe only two cardinal entities were observable, viz., matter and force. The universe was seen to consist actually of matter alone, albeit of many different kinds, and this matter, or materies, was found to be indestructible and non-reproducible. The doctrine of the conservation of matter was founded by Lavoisier.

Now this matter was found to be capable of changing its position in space, both absolutely and relatively to other matter: in other words it was capable of motion. And to effect this motion it was found that force had to be applied *directly* to the matter. Whatever influenced the motion of matter, whether by originating the motion,

or changing a pre-existing motion, or stopping the motion, was force. It was found that all matter offered a resistance to having its condition of motion, or no motion, changed, and this resistance to such a change was called *inertia*. It was further found that although matter at rest was *dead*, yet while in motion it carried a store of energy which could be abstracted from it and transferred elsewhere, while from the principle of the conservation of energy, since it possessed only a certain definite store, its energy was necessarily lessened by the exact amount which had been abstracted.

The universe, therefore, consists of matter, either dead or living, i.e., either at rest or in motion. And we may define force as that which influences the motion of matter, and thereby stores up energy in it, or abstracts energy from it. Force implies change of motion and energy, and vice versa. We must further recognize that a force cannot impart motion, and consequently store up energy, unless it acts *directly* on matter. It cannot act at a distance, as was until recently supposed. A body cannot exert a gravitational force upon another body through empty space, nor an electrical action, nor a magnetic action, nor an action of any kind. But it can and does exert such actions through intervening, closely connecting matter—in other words through a medium. It will be further seen that any action of a force upon matter must be of the nature of a *push*, and that a force cannot *drag* or *pull* matter into motion. The action must be directly towards the body acted upon, not away from it. To sum up the universe consists only of matter, plus force or motion or energy, as we please. There are only two factors—matter and the three cognate entities, force, motion or energy, which are only different expressions for a single underlying entity.*

* Ostwald has proposed, instead of recognizing only matter and force, to recognize only matter and energy. Such a contention is purely metaphysical and of no value.

It follows that in studying the action of bodies on each other at a distance, we must, if we wish to understand them, examine particularly the medium connecting them. For we have seen that there must be throughout a direct material connection between such bodies: otherwise no action can take place. When we hear a sound from a distant point we know that the action is transferred through the air. There is a continuous material chain between us and the sounding body. If there were a single break, or interruption of matter, at any point, by even an infinitesimal thickness, we should be unable to hear the sound. There was a time when the necessity of a continuous material connection for sound was not recognized. It was supposed to act at a distance—through nothing. And only very recently has the necessity of a continuous material connection, or medium, been recognized for all actions—electrical, magnetic, gravitational, etc. The medium, by, and through which, all the more important actions at a distance are carried on, is the Ether, and we shall now examine this chief medium of the universe.

The ether, both in volume and mass, constitutes overwhelmingly the greater part of the material universe. The amount of ordinary gross matter, or matter which is not ether, is almost infinitesimal in proportion, and yet it is only within a comparatively few years that man has become conscious of its existence. So far as we at present know, it has only three properties. It may have many more, but these, at least, are the only ones we have been able to recognize. It is a fluid, i.e., all bodies move freely through it, and it moves freely through the interstices of all bodies. It moves freely through intermolecular spaces, and even through intramolecular spaces. It penetrates through molecules, but not through atoms: so that it occupies all space with the exception of that occupied by the atoms of gross matter. It is always under a strain, or tension, exerting a very heavy pressure. It is capable

of compression and expansion, thereby varying its density. It is therefore elastic. It possesses enertia, and is therefore matter. It is capable of propagating a disturbance, thereby exhibiting in a combined form its two properties of elasticity and inertia, since these two qualities are necessary and sufficient for the transference of a disturbance. It should be stated that it has been held, and is even now held in some quarters, that the ether is devoid of elasticity, i.e., incompressible. This was to explain the seeming existence of transverse vibrations in this medium. But such an explanation is self-contradictory. If it were incompressible it could propagate no waves at all. Further a fluid cannot execute transverse vibrations, that being a property of solids. To meet this, it was stated that it was not a fluid, but a *kind* of solid. Thus its two manifest properties of fluidity and elasticity were denied to explain a supposed property of transmitting transverse vibrations—a property which it has never possessed and cannot possess. Even then the object is defeated, for, by removing its elasticity, all possibility of wave propagation is cut off. We shall see later on that the ether is capable of simulating transverse vibrations, but no true transverse vibrations are possible.

We have said that the ether is matter, but it differs most extraordinarily from ordinary gross matter. While ordinary matter is built up of discrete units—molecules and atoms—the ether seems to be a *continuum*. It is matter, but of a very simple kind; or matter reduced to its simplest terms. Its fluidity and continuity are not so much properties as negations of properties, since the discrete and solid and liquid properties of ordinary matter are highly differentiated conditions from a simple, elementary condition. Its elasticity may possibly be a concomitant and necessary adjunct of its inertia, so that these two properties may possibly represent a single fundamental and underlying property. Hence the ether

may be matter in its simplest form, from which all gross matter has been differentiated, and the single fundamental property of all matter may be simply inertia.

The ether has no internal friction, or viscosity, or any friction at all, a property which all gases possess; but since this property in gross matter is due to its molecular structure, it is naturally wanting in a *continuum*. A fluid without any friction or viscosity is called a *perfect* fluid, and hence the ether is the only *perfect* fluid. Differing so extraordinarily from gross matter, we may expect that its elasticity and inertia will differ extraordinarily from the corresponding properties in gross matter. And we find that such is the case. It is impossible to measure these quantities directly, but we may judge indirectly from their effects what the amount must be. The ratio of the elasticity to the density, or inertia, has been determined with some degree of exactness. In any medium, longitudinal waves, which are waves of a peculiar type, are propagated with a velocity which is equal to the square root of the elasticity divided by the density, or $V = \sqrt{\frac{E}{D}}$ (1). Now it is possible for a fluid medium to transmit disturbances of two totally different types, viz., waves with longitudinal vibrations, and what are known as electro-magnetic waves, with which we shall later on become familiar. The ratio $\frac{E}{D}$ has been determined by measuring the velocity of electro-magnetic disturbances in the ether, on the assumption that Equation (1) holds for such disturbances. Since the intimate mechanism of such waves was not then known, such an assumption was hardly warranted. There was no doubt that Equation (1) held for longitudinal waves, but it was not at all certain that electro-magnetic waves might not be propagated with a totally different velocity. However, it turns out, as we shall see, that all disturbances are propagated with prac-

tically the same velocity in an isotropic fluid medium. The square root of our ratio is something like 3×10^{10} centimeters per second, or about 186,000 miles per second. This shows that the pressure, or elasticity, of the ether must be extraordinarily high. What the actual values of the two quantities are, we do not yet certainly know, though we may make a guess. We may attempt a rough estimate from two phenomena—magnetism and cohesion. We shall see that magnetic lines of force are linear vortices in the ether, in the interior of which the pressure is considerably less than that of the general ether, and that magnetic "attraction" between two bodies is due to this general pressure striving to close the partial (or complete) vacuum. If we could obtain an absolute vacuum, then the force of such an attraction would be a measure of the general, or normal, ether pressure, and by Equation (1) we could obtain the density. Now the greatest magnetic force which it has as yet been possible to obtain, is something like 2000 pounds to the square inch, or roughly a ton to the square inch. The question arises, "How much of an absolute ether vacuum does this represent?" We shall see that under the enormous and sudden voltages employed in generating electro-magnetic waves, it is quite possible that actual ether vacua are attained in the axes of the magnetic lines of force, but in the *very* moderate and steady voltages employed in the lifting experiment described above, it is improbable that any great rarefaction can be obtained. Still we may say that it is probably $\frac{1}{1000}$ of a perfect vacuum, or something of that order. When we say "of that order," we mean that it is probably something like that, although it may vary by $\frac{1}{10}$ either way. If we could be tolerably sure of estimating its value within a tenth, that would be sufficient. Assuming that a force of 2000 pounds to the square inch corresponds to about $\frac{1}{1000}$ of a perfect vacuum, we should have, as the general

pressure of the ether, about 2,000,000 pounds to the square inch, which is 1.4×10^{11} dynes per square centimeter. This would make its density, by Equation (1), something like 10^{-10} that of water. This is probably somewhere near the truth showing that the ether has a most extraordinary tenuity, while exerting an enormous pressure. The pressure is intelligible when we reflect that it belongs to a single continuous mass, bounded only by the confines of the universe. This great resistance of the ether to compression has sometimes been referred to as its rigidity, which is manifestly a misuse of terms. The ether, being a perfect fluid, has, of course, no rigidity. A fluid under a pressure of a thousand pounds is no whit more rigid than when under a pressure of one pound.

We may consider then the density of all gross matter, or the density of all atoms, as roughly something like 10^{10} times that of the ether. Taking the view that the ether is the ground stuff out of which all forms of gross matter have been elaborated, it is evident that it must have been by some process of condensation, though under what conditions such an enormous condensation was effected, it seems difficult to imagine. If this view is correct, it is quite intelligible how the numerous infinite properties ascribed by the schoolmen to atoms, may be derived, viz., infinite hardness, unbreakableness, uncrushableness, infinite elasticity, infinite smoothness, and what not.

Assuming that the phenomenon of cohesion is due to the close co-aptation of the surfaces of atoms, which are thus pressed together by the total pressure of the ether, we find, for steel, that the cohesion or tenacity is something like 100 tons to the square inch. For unspun silk, which is the strongest substance we are acquainted with, it is nearly three times as much. This changes our estimate but little, so that we might consider the pressure of the ether as somewhere between 10^{10} and 10^{11} dynes per square centimeter, and its density as somewhere between

10^{-10} and 10^{-11} that of water, or of atoms in general. These estimates are to be considered rather as a minimum, and the actual values may be somewhat more.

Lodge, starting from Lord Kelvin's vortex theory of atoms, argues that as they occupy only a portion of the space bounding a body, and as they are the only material parts of the body, the density of the ether, which is a continuum, must be much greater than that of gross matter. He considers that the vortex rings which constitute the atoms have the identical density of the ether, but, as they are few and far between, the net density, as compared with the ether, is almost infinitesimal. According to his reckoning the pressure is 10^{33} dynes per square centimeter, which corresponds to an amount of energy equal to 10^{33} ergs in every cubic centimeter. The density is 10^{12}. Taking only a cubic millimeter of space, the ether energy in this small space he states to be "Equal to the energy of a million horse-power station working continuously for forty million years." And there is, in a cubic millimeter, "A mass equivalent to what, if it were matter, we should call 1000 tons." This estimate is too low, for the density of a vortex ring is not that of the general ether, but much less.

It is hardly necessary to say that the vortex theory of atoms is not a very safe hypothesis to start from, even though Lodge argues that "It is so good that it deserves to be true." It is doubtful if Lord Kelvin himself ever considered it more than a "curious speculation." We shall show later on that gross matter must be very much more dense than the ether.

In our further study of the ether, it is evident that we can only become aware of the existence of this medium through its motion. Dead ether, or ether at rest, can in no way affect our senses, either directly or indirectly; so that we are now forced to inquire into what kinds of motion are possible in such a material as we know the ether to be. Generally, we may say there is only one kind of motion—a motion of certain portions relatively to others, or a streaming or flowing of certain portions past others, constituting ether currents. Whether the ether ever streams over great distances, as seems indicated by the immense spiral nebulæ, where gross matter may be in the process of condensation and worlds are being formed, lies beyond

our present scope. We shall confine ourselves to cases where it flows from a point of higher pressure to a point of lower pressure over finite distances, as in conductors: and over infinitesimal distances in the free ether. In the free ether there may be a flow over very short distances from a point of higher pressure to one of lower pressure, consisting of a surging backward and forward between a condition of compression to one of rarefaction. Such short alternating ether currents are the essence of all longitudinal waves, and we know that such waves must exist in a fluid like the ether, possessing both elasticity and inertia. Further linear vortices may exist in such a medium, consisting of closed current sheets surrounding an axis of lesser density than the general ether. And such linear vortices will persist indefinitely, since there is no friction in the ether between its different parts. The excess pressure of the external ether is supported by the centrifugal force of the rapidly rotating current sheet. Or, designating the outward centrifugal force of the current sheet per unit of surface by f, and the interior pressure by P_1, while the external, or normal pressure is P, $f = P - P_1$. These linear vortices will always form closed curves, for while it is conceivable that the two ends of a vortex filament might be closed by two atoms, or by two continuous surfaces of atoms—the only bodies impermeable to the ether—we do not know certainly of any such instances.

There are further two ways in which a disturbance may be propagated in such a medium, viz., by longitudinal waves of the well-known form, and by the translation through the ether of such vortex rings as we have just considered, constituting what are known as electromagnetic waves.

The above varieties of motion are the only ones possible in such a medium, and we may tabulate them as follows:

1. Simple currents, where the ether moves in an effort to relieve an increased pressure, driven, as we say, by an

electro-motive force: or where the ether continues in motion from its own inertia, without any driving force and meeting with no resistance, such as is the case with the current sheets in our vortex rings.

2. Longitudinal waves, which are propagated by a series of regularly alternating currents in the direction of the wave.

3. Electro-magnetic waves, which consist of a spreading out of vortex rings through space.

LONGITUDINAL WAVES IN THE ETHER

We shall first consider longitudinal waves in the ether, which, since their perfect analogy is found in air waves, have happily been completely studied. Since a fluid medium, whether a gas or the ether, possesses inertia, any thrust against it will be resisted just as much as if it were a solid. The reaction will be equal and opposite to the action. Since it is elastic, the medium will be compressed between these two forces acting in opposite directions; and since it is free to move, it will move also in the direction of the force. The action of the thrust is therefore double. It sets the medium in motion and at the same time compresses it, in each process doing work and thereby storing up energy in the medium. The first kind of energy is called kinetic energy and the energy of compression is called potential energy. This latter form of energy is also, in the last analysis, kinetic, or due to motion, though this motion is concealed and not as manifestly evident to the senses. Thus the energy of a compressed gas, or its potential energy, is due to the motion of its molecules, for we have seen that energy and motion are inseparable. Likewise the pressure of the ether indicates a huge store of potential energy, which must be due to motion of some sort, though of the nature of this motion, we are as yet in complete ignorance. It may

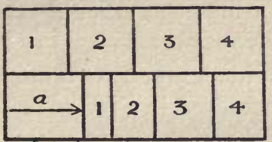

Fig. 1

possibly be due to extremely minute vortices pressed together, their current sheets moving with the standard velocity of the medium, in which case the ether would be a discrete structure. Such a structure would enable it to have very great energy (pressure) with little mass, for energy consists of two factors—mass and motion. Beyond the normal pressure, at some point which we might call the critical pressure, it might be possible to break down these vortices and condense them into non-vortical gross matter. But every indication seems to point against a discrete structure, and rather to a continuum, in which case the energy may possibly be due to a general pulsation throughout its mass. We shall consider the ether a continuum, avoiding all speculation as to its internal motion.

Let us suppose our medium divided off into laminæ of equal thickness, 1,2, 3, 4, as represented in Fig. 1. Let us further suppose that lamina 1 has been thrust by a force to the right, thereby having imparted to it the two forms of energy described above. It is evident that these two forms of energy will be limited at the first short interval of time to the immediate vicinity of the thrust, but as time goes on the changed portions of the medium will shift their positions and the disturbance will travel along as a wave. The lower portion of Fig. 1 indicates the instantaneous position and condition of the laminæ after a certain interval of time has elapsed. The disturbance has extended to the outer boundary of 4, but not beyond. Let v_1, v_2, v_3, v_4, be the velocities of the laminæ at any instant, and c_1, c_2, c_3, c_4, the distances through which they have been compressed. Now every lamina opposes to compression the original pressure it possessed, which is the normal pressure of the medium, and which we will designate by P, plus the resistance of its inertia. Or the compressional force is $P+m\,\dfrac{dv}{dt}$, where m is the mass of the lamina. The work of compression will therefore be

$\sum\left(P+m\frac{dv}{dt}\right)dc$. On lamina 4, this work will be $\sum\left(P+m\frac{dv_4}{dt}\right)dc_4 = Pc_4 + \frac{mv_4^2}{2}$, where v_4 represents the velocity of the lamina at the instant we are considering, with corresponding expressions for the other laminæ. Hence, designating the potential energy at any point, at any instant, by W, and the kinetic energy by T, we have $W = Pc + \mathrm{T}$. Or the potential energy is equal to the normal pressure into the distance the lamina has been compressed, plus its kinetic energy. In other words, the kinetic energy of a lamina is equal to the work of compression done upon it *in excess* of the work done by the normal pressure. The wave set up before such a single thrust is known as a compressional, or *positive*, wave. It travels along with a uniform velocity, compressing and moving along successively all parts of the medium in its path, and leaving them at rest, but set down at a certain definite distance from their original position, viz., the distance, or *amplitude*, of the thrust.

Referring again to Fig. 1, it will be seen that while the medium to the right, against which the thrust was made, transmits a compressional wave with uniform velocity in the direction of the thrust, the medium to the left, away from which the thrust was made, will equally transmit an expansional wave, towards the left. And by the same reasoning as before, the work of expansion at any point will be equal to the kinetic energy at that point, plus the work done against the normal pressure during the expansion. In either case, we have the formula $W = Pc + \mathrm{T}$.

If we thrust the lamina 1 forward and backward, always through the same limits, we have what is called a vibrational wave. After one complete excursion forward and back, it is evident that no work will have been done by the normal pressure, or $\sum dc = o$. Hence the term Pc

vanishes, and for a complete or finished vibration, the total potential energy of the wave will be equal to the total kinetic energy. The average kinetic energy, or the average potential energy, is half of its maximum value. Hence the whole energy, if represented by a single form, would be equal to the maximum value of that form distributed throughout the whole wave. As *Lord Rayleigh puts it "In a progressive wave of any type one-half of the energy is potential and one-half is kinetic. The total energy of the wave is equal to the energy derived from compressing its whole mass from its minimum to its maximum density, or to the energy of the whole mass moving with its maximum velocity."

This is an important general principle in nature, viz., that where no hindrance is opposed, or where two kinds of energy are free to change or flow into each other, they always become equal. The wave contains a certain definite quantity of energy divided into two parts. The potential energy always strives to release itself into kinetic energy, but when an equalization has been effected, no more potential energy can flow into kinetic energy, and vice versa, since no form of energy can rise above its source.

The intimate structure of a longitudinal vibrational wave is shown in Fig. 2.

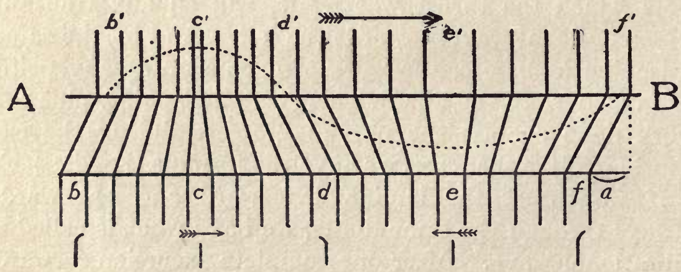

Fig. 2

* Lord Rayleigh. Theory of Sound. Par. 245.

The equal laminæ in the lower part represent the medium at rest, and the upper part shows the transposition and compression of these same laminæ at a certain instant during the passage of a wave The dotted curve represents graphically the density at different points, the compression or rarefaction being proportional respectively to its height above or below the line AB. The positions of the prong of a tuning fork corresponding to the several points of the wave are shown below. The laminæ in the forward or rarefactional part of the wave are moving backward, while the laminæ in the rearward half are all moving forward, as indicated by the small arrows. The distance a, or the extreme distance which a particle moves on either side from its position of equilibrium, is called the amplitude of the wave. The extreme lamina f^1 has just come to rest and its normal density, after swinging forward through the amplitude a, and is just preparing to swing back. Its subsequent positions relatively to its position of equilibrium, and its density, are shown by the successive laminæ in the rear. The disturbance is supposed to be progressing towards the right, as shown by the large arrow, having originated at some point to the left. But it is possible for a wave to proceed outward from a disturbance with its compressed parts moving backward, and its rarefied parts moving forward. Thus if we had a membrane containing a compressed gas, with a vibrating body in the interior giving off waves with the compressed halves moving outward, we should expect the waves leaving its surface to have the motions of their respective halves reversed. For the compressed half, when passing through the membrane escapes into a rarer medium and expands suddenly, while the expanded half moving backward, towards the membrane, does so against a higher pressure and should be compressed. On the other hand, if the pressure within the membrane is lower than that of the outside medium, the motion of the respective halves

should be unaltered. In both cases the waves proceed regularly outward, away from the disturbing body, but with this peculiar difference, viz., that the directions of the motion of their compressed and rarefied halves are reversed. We shall, conventionally, define a wave with its compressed portions moving away from the disturbing source, as a *positive* wave; and a wave with its condensed parts moving towards the disturbing source as a *negative* wave. A single compressional wave, due to a unidirectional thrust (explosion) has sometimes been called a positive wave, and a single unidirectional expansive wave has accordingly been termed a negative wave. Our definition above, however, applies only to bidirectional, or vibratory, waves.

If we should expand one-half of a wave from its original length $\frac{l}{2}$, where l is the length of the wave, to its actual length in the expanded half, which is $\frac{l}{2} + 2a$, and should likewise compress the other half from its original length $\frac{l}{2}$ to its actual length $\frac{l}{2} - 2a$, the energy so expanded would clearly be equal to the compressional or potential energy of the wave. The work of expanding $\frac{l}{2}$ to $\frac{l}{2} + 2a$ is, since the pressure is inversely as the volume, or $p = P\frac{l}{l+2c}$, where c is the expansion, $W = Pl\int_0^{2a}\frac{dc}{l+2c} = P\frac{l}{2}\log\frac{l}{l+4a}$.

Developing the logarithm by Maclaurin's theorem, and neglecting higher powers of a, since the amplitude is supposed to be small, we have $W = -2\,Pa + \frac{4\,Pa^2}{l}$.

Likewise the work of compression, from a length $\frac{l}{2}$ to a length $\frac{l}{2}-2a$, is $W = 2\,Pa + \frac{4Pa^2}{l}$. The total potential energy in the wave is, therefore, $\frac{8Pa^2}{l}$. Considering a unit cross section of the wave, its mass is Dl, where D is the normal density of the medium. Let v be the average velocity of a lamina during a complete vibration. Then since a lamina traverses a distance $4a$ while the wave progresses a wave length, l, and designating the velocity of the wave by V, we have $\underline{v} = \frac{4aV}{l}$. The total kinetic energy of the wave is $\frac{Dl\underline{v}^2}{2} = \frac{8a^2DV^2}{l}$. But this must be equal to the total potential energy. Hence $V = \sqrt{\frac{P}{D}}$.

There is a difference between a gaseous medium and the ether in that the molecules take up a part of the space and the compression is not actually measured by the ratio of $\frac{l}{2}-2a$ to $\frac{l}{2}$. The formula for a gas becomes $V = \sqrt{k\,\frac{P}{D}}$, where k is the ratio of the two specific heats. (See "The Atmosphere," by the author.) The motion of the molecules of gross matter constitutes the phenomenon of heat, and since the ether, as far as we know, is a continuous medium, such a thing as heat is foreign to its nature. The ether can be neither hot nor cold, although it transmits vibrations from gross matter which render other bodies hot or cold.

The formula $V = \sqrt{\frac{P}{D}}$ is an important one for all media. It must be remembered that it holds only where the amplitudes are so small that powers above the square may be

neglected. Where the amplitudes are so great that higher powers cannot be neglected, the velocity of propagation of a disturbance may be very much greater. Thus in the air, violent unidirectional disturbances, such as explosions, may be propagated with very high velocities, the velocity increasing with the intensity and suddenness of the thrust. The same is true of the ether, and the standard velocity, $V = 3 \times 10^{10} \frac{\text{cms.}}{\text{sec.}}$, holds good only for longitudinal waves of small amplitude. Disturbance can be propagated with a much higher velocity, although not with a lower velocity in the case of longitudinal waves.

We have said that the ether is without viscosity: it is frictionless. But when a stream or current of ether impinges upon an impermeable surface, it must exercise a pressure upon such a surface. It flows freely between and through molecules, but not through atoms. The space occupied by atoms is not occupied by ether, and the ether must flow around such bodies.

We shall assume that the pressure exerted on a surface S is proportional to the density of the ether current, and to the velocity with which the current is flowing, so that we may write $p = vDS$. When a current of ether is flowing in a conductor it has to make its way past the atoms and thus exerts a pressure upon them. A counter pressure is equally exerted upon the current which is thus *resisted* to this extent. Let us call the electro-motive force, or the driving pressure, or the pressure gradient, E. The current starts from zero velocity and rapidly increases its velocity. Calling the mass of ether which flows through a cross section of the conductor in unit time m, we have $E - p = E - vDS = m\frac{dv}{dt}$. The current will increase until the resulting driving force, or the acceleration becomes zero. When this point is reached, the

velocity of the current becomes uniform. The condition for such a state is $E = vDS$. Let us call the back pressure, or resistance, when unit mass of ether is flowing in unit time, R. The value of R will naturally depend on the total atomic surface opposing the flow, and will be different for different substances. We can write our condition, then, $E = vDR$ or $vD = \frac{E}{R}$. But vD is the mass or quantity of ether which is flowing through a cross section of the conductor in unit time, and this measures the current strength. Calling the quantity of ether flowing in unit time C, we have $C = \frac{E}{R}$, which is Ohm's law. This law confirms exactly, experimentally, our assumption, then, that $p = vDS$. Ohm's law not only states the axiom that when a current is constant, or flowing with a uniform velocity, it has no acceleration, but it also states that the resistance is proportional to the quantity or mass of ether flowing in unit time. The resistance thus measures a velocity as well as a density. Theoretically the condition of equilibrium would never be reached. Practically it is reached in a very short time. The driving force of the current does work in overcoming the resistance offered by the atomic surfaces. In overcoming this resistance it sets the atoms into vibration about their positions of equilibrium, with the result that the energy of the current, which is EC, becomes transformed into kinetic energy of the atoms (molecules). In a fluid conductor (mercury), this pressure results in visible motion, as seen in electro-capillary phenomena. C representing the mass of ether flowing in unit time, the atomic kinetic energy, or the heat developed, is proportional to ECt, which is known as Joule's law.

Returning to Fig. 2, it is evident that the velocity of the flow of the expanded ether in the wave must be

slightly greater than that of the compressed ether. It is further evident that the average velocities in the two halves must be inversely as the densities. Thus the condensed ether in the compressed half flows a little more slowly than the rarer ether in the expanded half; but as the pressure exerted upon a surface is proportional to the density and the velocity, we are led to the important result that the average pressures exerted upon a surface are the same in both halves.

Let us suppose that a particle denser than the ether is in the path of a longitudinal wave. As the condensed half of the wave sweeps over it it will urge the particle forward. Let $\underline{v}$ be the average velocity of the ether particles, and $\underline{v}^1$ the average velocity of the denser particle during the passage of the condensed half of the wave. Evidently the denser particle will lag behind the ether particles. We shall assume that $Dv = D^1v^1$, where D and D^1 are the respective densities, or the average velocities will be inversely as the densities. Let s be the distance which the denser particle has moved, while an ether particle has moved $2a$, thus completing a half wave. If M is the mass of the denser particle, and m the mass of an equal volume of ether, then $Ms = 2am$. Their distance apart at the end of a half swing will be, therefore, $2a\left(\frac{M-m}{M}\right)$. Likewise, on the backward swing, the denser particle and a corresponding mass of ether, starting from rest, will, at the end of the swing be the same distance apart. Or the denser particle always lags a distance $2a\left(\frac{M-m}{M}\right)$ behind the corresponding ether particle. The time taken by each half wave to clear the ether particle is $\frac{l}{2V}$, while

the time taken by the compressed half to clear the denser particle is $\frac{l}{2V} - \frac{2a(M-m)}{MV}$, and the time taken by the expansional half to clear the denser particle is

$$\frac{l}{2V} + \frac{2a\,(M-m)}{MV}.$$

The current pressure, therefore, which is $D\underline{v}$, acts for a shorter time upon the denser particle during the passage of the condensed half, and for a longer time during the passage of the expanded half. It is evident that the pressure gradient which is equal on both sides and acts for the same time can have no effect. The net result, then, is that a backward pressure, equal to $D\underline{v}$, acts for a time equal to $\frac{4a(M-m)}{MV}$ during the passage of every complete wave. This will be equivalent to a backward acceleration, acting continuously, of

$$\frac{D\underline{v}}{t} \cdot \frac{4a\,(M-m)}{MV},$$

where t is the time of a complete vibration.

$$D\underline{v} \cdot \frac{4a\,(M-m)}{M\,V\,t} = D \cdot \frac{16a^2}{l} \cdot \frac{(M-m)}{M\,t} = D\underline{v} \cdot \frac{4a\,(M-m)}{M\,l}.$$

Measuring the density of the ether by its pressure, P, we have $M\frac{dv}{dt} = \frac{P16a^2}{l} \cdot \frac{(M-m)}{M\,t} = \frac{E(M-m)}{M\,t}$, where E is the total energy in a complete wave per unit cross section. We have already seen that $E = P\,\frac{16a^2}{l}$.

If $M < m$, the acceleration becomes reversed, and we see that a body less dense than the ether will be urged forward in the direction of the motion of the condensed half. This is evident, since, in this case the compressed half will act upon the body longer than the expanded half by a time equal to $\frac{4a\,(M-m)}{MV}$. If the particle consists of matter very much denser than the ether, as is the case with all gross matter, the fraction, $\frac{M-m}{M}$, becomes practically unity, and the force will be $\frac{E}{t}$. Every atom of gross matter, therefore, which sends out positive longitudinal waves, and these are the only kind of longitudinal waves which atoms are capable of radiating, will attract every other atom with a force $\frac{E}{t}S$, where S is the surface of the attracted atom.

If the waves radiate from a spherical surface S_1, $\frac{E}{t}S_1$ measures the flow of energy from its surface in unit time, and this flow through all other concentric spherical surfaces remains constant. Hence the attraction of such a body on all spherical shells surrounding it is constant, and equal to the total outflow of energy in unit time.

Since every atom in an attracting body sends out such waves, the total attraction will be proportional to the mass of the body, and since the total surface of the atoms acted upon in the attracted body is proportional to the number of atoms, or to its mass, the total attraction is proportional to $\frac{MM^1E}{t}$.

Since the total wave energy flowing through any spherical surface, surrounding the disturbing source, in unit time, remains constant, the wave energy at any point, or its intensity per unit of surface, varies inversely as the square of the distance. Hence the attraction of a body on a distant body is proportional to $\frac{MM^1}{r^2} \cdot \frac{E}{t}$, where r is the distance between them. This is Newton's law. We have kept the term attraction because it is sanctioned by long usage, but it must be remembered that in nature there is no such thing as a *drawing* of bodies together. It is a "vis a tergo," or a *pushing* together, the forces being applied to the surfaces of the atoms.

If the attracted body is *dead*, i.e., not sending out any waves, it can exert no attraction, but is simply attracted. If both bodies are alive—radiating waves—their attractions on each other are respectively $\frac{MM^1}{r^2} \cdot \frac{E}{t}$ and $\frac{MM^1}{r^2} \cdot \frac{E^1}{t^1}$. Where $E = E^1$ and $t = t^1$, the mutual attractions are equal. Both the wave energy sent out by a vibrating atom, and the action of such waves on an atom are proportional to their surfaces, or cross sections. Whether all atoms radiate waves of the same frequency and containing the same amount of energy per unit of radiating surface, we do not know. If their motion (vibration) is derived from the internal motion of the ether, as seems possible, such would be the case. We should have a case, then, analogous to the Brownian vibrations seen in small material particles suspended in a liquid, where the invisible internal motion of the molecules becomes visible in the larger particles. We shall see that the motion to and fro of an atom results in the radiation of an electromagnetic, or heat, wave, and a longitudinal wave at right angles to it. If such stronger longitudinal waves are the

only ones participating in attraction we should expect the attraction to be a function of the temperature of a body, so that a body at the absolute zero would be attracted but could not attract. But of all these matters we are in complete ignorance. It is to be remarked, however, that the energies radiated by the two kinds of waves are not equal and that with increasing frequencies of the vibrations the energy passes off almost exclusively in electro-magnetic waves.

Where $M < m$, we have seen that there is repulsion instead of attraction. Since in this case, the bodies acted upon have a density less than that of the ether, their inertia is very slight and they are driven almost immediately to their limiting velocity, which is that of the wave itself. Comets' tails and the corona of the sun must represent some form of extremely tenuous matter, since they are repelled with the velocity of light.

If the attracted body is moving, then a Doppler effect will result. If moving against the waves, then more waves will pass it in a given time, and the frequency will be raised factitively. t will become relatively smaller and the attraction increases. If the attracted body is moving with the wave, for the same reason the attraction will become less. But the frequency of all longitudinal waves in the ether is so extremely high, that a few miles more or less of relative velocity is wholly negligible. The greatest velocities so far observed for dense matter among the heavenly bodies hardly exceeds 200 miles per second. Compared with the enormous velocity of wave propagation, viz., 186,000 miles per second, this is insignificant.

We have seen that the attraction exerted by a wave upon an atom is $\frac{ES}{t}$. Since we find that different kinds of atoms have different "weights" or are acted upon more strongly by the same waves, they must have different

average cross sections. A priori it would be highly improbable that all atoms should have the same average cross section. Hence, we are justified in inferring that, since their atomic weights vary through a range of from 1 to 238, their average cross sections must vary through a like range, and their linear dimensions must vary through a range of from 1 to 16. But we are not justified in inferring anything as to their size or shape, or anything else beyond this.

Possibly, if it is true, as is generally believed, that in the crystalline state, atoms arrange themselves symmetrically, and if it were found that crystals weighed more when pointed in one direction than in another, we might infer that their dimensions in one direction were greater than in another. But nothing of the sort has ever been found, or even tried.

We may sum up the results so far obtained as follows: The attraction and repulsion of bodies at a distance, such as is everywhere observed, can only take place through a medium. Without a medium, no action at a distance would be possible. Various actions—gravitational, electrical, magnetic, etc.—are effected without the interposition of gross matter, and it is certain that these actions are transmitted through the ether. Motion can only arise from motion: hence these actions are transmitted by motion of some kind in the ether. All motions that are possible in a medium do occur. The only possible motions in a fluid medium are three.

1. Translational motion, or a streaming of the medium. We can effect motion at a distance by striking an object with a projectile.

2. A peculiar kind of alternate streaming in opposite directions, constituting longitudinal waves. We have seen that such a motion is capable of effecting attractions and repulsions.

3. Vortex motion. We shall examine this form of

motion, which consists of streaming in closed curves, directly. We shall see that while this form of motion is capable of causing attractions and repulsions of a peculiar nature, which we recognize as magnetic, they are incapable of causing the general attractions and repulsions with which we are familiar. As stated before, we have omitted a general vortex motion of the ether, not in closed curves, such as possibly has led to the formation of celestial systems (spiral nebulæ and solar systems), as not lying within our present scope.

Hence gravitational attraction must be due to longitudinal waves. Since the amount of wave energy flowing through a closed surface remains constant, its concentration, or intensity, is inversely proportional to the square of the distance. Whence Newton's law follows, viz., the attraction between two bodies is proportional to the product of their masses, and inversely proportional to the square of the distance between them.

The wave force $\frac{ES}{t}$, which includes both attraction and repulsion, may perhaps best be called the differential inertianal pressure. Gravitational pressure implies gross matter, but we shall see that condensed and rarefied ether is equally subject to this force. We shall find that a mass of condensed ether, or a positive charge of electricity, gives off only negative waves, while a mass of rarefied ether, or a negative charge of electricity, gives off only positive waves. Hence all gross matter attracts all other gross matter and all masses of condensed ether, while repelling all masses of rarefied ether. On the other hand condensed ether repels condensed ether and attracts rarefied ether, while rarefied ether repels rarefied ether and attracts condensed ether.

VORTEX FILAMENTS IN THE ETHER

In all elastic fluids, vortex filaments are readily formed. The condition is simply that a rotating sheet of the fluid shall by its centrifugal force support the excess of pressure of the general medium over the lessened pressure in the interior. In a gas, friction soon reduces the rotational energy of the sheet, so that they cannot long persist: but in the ether, which has no viscosity, such vortices persist indefinitely and would persist forever unless destroyed under special conditions which we shall investigate later. In an incompressible liquid, and all liquids are little compressible, apart from friction, the formation and persistance of linear vortices is rendered difficult because the necessary lessened pressure in the interior, which holds the outer rotating sheet, can hardly be attained short of a complete vacuum in the axis. In a gaseous medium a linear vortex need not be a closed curve, provided its two ends are shut off by surfaces impermeable to the medium; but in the ether such linear vortices always form closed complete rings.

Such vortex rings are very familiar to us. A locomotive puffs them out of its smoke stack, and, when they are accompanied by smoke, they are visible; otherwise not. Smokers learn how to blow them. They accompany the blast of a gun; visible with black powder; invisible with smokeless. They are easily made by tapping smoke out of a box through a circular orifice. This formation is not to be explained as due to the friction of the gas on the

edges of the orifice. All gases, of course, are subject to friction, but this is very slight. It is due to a stoppage and diversion of the currents at and in the vicinity of the edge, while the central stream flows on unobstructed. Certain currents at the edges are stopped and even begin to flow backward. A line of lessened pressure forms, and the central streams are pushed back over this and by their momentum are carried around it. Once formed, it must persist, unless, as in the case of gases, its energy is used up by friction. In a conductor the molecules are more densely packed together near the surface than in the interior. This is especially marked *at* the surface where a peculiar differentiated condition exists which is known as a "surface tension." The mutual attraction of the molecules is here all towards the interior with no counterbalancing action from the exterior. In the centre, the attractions oppose each other from all directions so that here the density and tenacity are least. It is for this reason that a wire cable is much stronger than a rod of the same material of equal cross section. The flow of a steady electric current is greater in the axis of a conductor than in the peripheral portions. Hence we have a condition favorable to the formation of vortices. The current is less obstructed in the centre, and more obstructed in the peripheral portions, so that it is natural to expect that vortex rings of ether will be thrown off surrounding the conductor. And, in fact, we find that whenever a current is flowing in a conductor, it is always surrounded by such vortex rings. Further such rings are always rotating in such a direction that the inner edge of the ring moves in the direction of the current which formed it, while the outer edge moves in the opposite direction.

A small length of a vortex filament may be regarded as a cylinder made up of an infinite number of concentric cylindrical sheets, each rotating with an angular velocity, ω. The pressure at the surface is the normal ether pres-

sure, P. The increment of pressure outward from the axis, due to the centrifugal force, is $dp = \rho dr \cdot r\omega^2$. The density, $\rho = \frac{p}{P}$. Hence $\log \frac{p}{P} = \frac{\omega^2}{2}\left(r^2 - a^2\right)$, a being the radius of the cylinder. The pressure falls logarithmically from the surface to the axis, the fall increasing as the square of the angular velocity.

Let us suppose that the original whirl imparted to the vortex was violent enough to cause a complete vacuum in the axis, or the filament consists of a current sheet surrounding a complete vacuum. The normal pressure of the current sheet is P at every point, and therefore the filament cannot collapse about its axis, but there is also a lateral pressure, P, which is unsupported, and which therefore tends to expand the circumference of the ring. The absolute potential energy of the current sheet, or its potential energy measured from an absolute zero, is half its pressure into its volume. Taking, h, as the thickness of the sheet, and S as its surface, its total potential energy is $\frac{PSh}{2} = \frac{Pu}{2}$, where u is the volume of the sheet. Now the moment of momentum of the sheet, or $mr^2\omega$, will remain constant, but the thickness of the sheet, h, and r will diminish as the ring expands. However the volume of the sheet u, and its total potential energy $\frac{Pu}{2}$, will remain constant. This potential energy tends to expand the ring and thereby to impart kinetic energy to it as a whole. It does not, however, lose its energy by so doing, since it is automatically kept at a constant point, by drawing from the rotational energy whatever it loses as kinetic energy. It is evident that when the kinetic energy of the ring becomes equal to the potential energy of the

sheet, a condition of equilibrium will have been reached, and there is no further exchange between the energies. At this point $\frac{mV^2}{2} = \frac{Pu}{2}$, or $V = \sqrt{\frac{P}{\frac{m}{u}}} = \sqrt{\frac{P}{D}}$, and we see that the ring will spread out with the standard velocity.

This is on the supposition that its flight is unresisted. We have seen that any body moving through the ether must be resisted by an amount proportional to the velocity with which it moves, and to the surface which it opposes. A single ring, therefore, no matter with what velocity it is thrown out, must soon come to rest, or move so slowly that the resistance it experiences does not overcome the expansive effort of the potential energy. However, in opposing the resistance, it throws up a compression wave in front and an expansion wave behind, and these longitudinal waves travel ahead with the standard velocity. If the foremost ring is lagging, it is overtaken by these waves from the rings which have been given off subsequently, and since it is a body less dense than the ether, it will be urged on by these waves and quickly take their step. The result is that all the rings will almost immediately be moving out with their natural velocity, as if they were unresisted, and in fact they are unresisted for the effect of the longitudinal waves which they set up is to cause the ether to move with them at the standard velocity.

The ring cannot collapse about the axis of the filament because the pressure of the external ether, P, is balanced at every point of its surface by an equal and opposite centrifugal force. There is, however, a differential external pressure tending to compress the ring into a smaller circle. For calling the distance from the centre of the ring to the axis threading the filament, R, and the radius of a cross section, r, let us cut the ring into two parts by a vertical cylinder passing through the axis of the filament.

The component of the surface parallel to the cylinder on the inner side is $2\pi\int_{-r}^{+r}(R-x)\,dy = 2\pi\int_{-r}^{+r}(R-\sqrt{r^2-y^2})\,dy$

$= 4\pi rR - \pi^2r^2$. Likewise the component of the outer surface parallel to the cylinder is $4\pi rR + \pi^2r^2$. Hence the differential pressure inward is $2\,P\pi^2r^2$.

Taking the case of a vortex with a central vacuum where the expansional pressure of the current sheet is P, this is equivalent by Laplace's formula to a radial pressure outward of $\frac{P}{R}$. The total amount of this pressure outward is evidently $\frac{P}{R}\,.\,4\pi rR = P\,.\,4\pi r$. Where r is so small that we can neglect its square in comparison with its first power, the differential external pressure, $2P\pi^2r^2$, is negligible. But when a vacuum does not exist in the axis, and the average pressure of the sheets is below P and r comparatively large, it is evident that a position will generally be found where the expansional pressure will be exactly balanced by the differential external pressure, and in this position the ring will remain stationary.

In a vortex filament with a central vacuum the centrifugal force per unit of surface must equal the external pressure. The surface of the ring is $4\pi^2rR$ and its volume, U, is $2\pi^2r^2R$. Hence

$$\frac{mr\omega^2}{4\pi^2rR} = P, \text{ and } \frac{mr^2\omega^2}{2} = PU = \frac{mv^2}{2},$$

where v is the velocity of the current sheet. Or $v = \sqrt{\frac{2P}{\frac{m}{u}}} = \sqrt{\frac{2P}{D^1}}$. D^1 is the average density of the ring, and is less than that of the normal ether. The velo-

city of the current sheet must therefore be greater than the standard velocity. PU measures the rotational, or magnetic, energy of the vortex.

The formula $V = \sqrt{\frac{P}{D}}$ is an important one in our theory. It is the velocity with which longitudinal waves of small amplitude are propagated, as well as that of electro-magnetic waves. However, vortices without vacua may move rather slowly. There is a position of equilibrium where for low-rotational vortices the differential external pressure balances the interior expansional pressure. A vortex generated about a wire carrying a current may move out comparatively slowly, and the lower limit of such a velocity is evidently zero, or a vortex may be generated in a position of equilibrium.

When the vortices are generated under a moderate pressure which rises with no great suddenness, the rotational energies will be low—far under the vacuum point—and the rings proceed to their position of equilibrium which they maintain when the current becomes steady. The position of equilibrium is not now the one we have pointed out for a single filament, but, since vortex lines when pressed together exert a lateral pressure on each other, the figure of equilibrium will be the resultant of all these lateral pressures. It is evident that when such a tube becomes compressed the centrifugal force increases, since the moment of momentum of the current sheet, or $mr^2\omega$, must remain constant.

Let us suppose that we have applied an electro-motive force to a conductor—say a *charge* of positive electricity, or condensed ether, has been applied to one end, and a *charge* of negative electricity, or expanded ether, to the other end, thereby establishing a pressure gradient. An equilibrium of pressure is quickly established. In a certain metaphysical sense, it might be considered that

not only has positive electricity flowed in one direction but negative electricity has also flowed in the opposite direction, and such is still the general conception, although the convention has been made that the direction in which the positive electricity flows shall be considered the direction of the current. Actually, however, no negative electricity flows here, any more than, when we compress a gas in one globe and exhaust it in another, and connect them, the rarefied gas flows into the compressed gas. The simple unquestionable fact is that condensed ether has expanded into rarefied ether—positive into negative. In nature motion can only take place in the direction of a force, not against it.

We have started our current, but it does not reach its full strength at once. It is delayed for a time while it is building up its system of concentric vortices surrounding the conductor. As layer after layer of the rings are being shot out, and succeeding layers are being sub-posed, the pressure, or electro-motive force, is doing considerable work, both in manufacturing the partial vacua and in pushing them away from the wire. It consequently can expend only a part of its energy in propelling the current against the resistance offered by the atomic surfaces.

The field of vortex lines, or the magnetic field, throws the medium surrounding the wire into a state of strain. There is a force pressing radially from all directions upon the wire, which is balanced by the pressure of the current. There is also a pressure along the vortex filaments and they behave as if they were tense strings, always striving to shorten themselves. We have already pointed out how it is possible for a fluid, isotropic medium to be put under strains in particular directions by motion.

The current finally becomes steady. There is now a condition of equilibrium and the rings remain stationary. The driving force is exactly balanced by the resistance, or counterpressure, as stated in Ohm's law. But if the cur-

rent again increases, the whole system moves outward again, and a new set of rings is shoved under them, until a new condition of equilibrium is established. If the current decreases, the ring system falls back towards the wire, and the innermost are absorbed again into the current from which they sprang.

The vortex filaments are lines of magnetic force. Every current must be accompanied by a magnetic field*, and the currents represented by the current sheets have their magnetic field wholly internal. The direction of the magnetic force (or line) is perpendicular to the direction of the current and this condition must necessarily exist under all circumstances. If we twist a wire into a spiral coil and send a current through it, the circular lines of magnetic force which surround a straight wire, will, in this case, become merged into a system of closed lines threading the coil through its interior, and the direction of rotation in the vortices will depend upon the direction of the current. The magnetic lines and current direction are perpendicular to each other, as always.

Let us suppose a vortex ring just touching the wire with its inner edge. It is pressing upon the wire with a certain force, but this pressure is exactly balanced by the pressure of the ether in the current and the ring consequently cannot contract. But if the pressure in the current falls, the ring begins to contract into the wire. But instead of doing this, it rolls itself out into a linear current on the surface of the wire in the direction of the original current.

This falling back of the vortices upon the wire when the current decreases, or is broken, is called self-induction, or the "extra current on break." It has been supposed that it was due to the inertia of electricity. Undoubtedly the ether has inertia, but it is very slight. Practically all of the extra current is due to the discharge of the energy

* Linear currents in the free ether are the sole exception.

stored up in the magnetic field surrounding the wire. The building up of this field takes some time, comparatively speaking, while its collapse on breaking the current (or wire) is sudden, though not instantaneous. No action in nature can take place instantaneously, although it has been the custom to consider gravitation an instantaneous action.

The vortex lines which are thrown off by a current under moderate pressure and formed with no great suddenness, have, as we have seen, only partial vacua, and do not go to great distances from the wire, even theoretically. They do not extend indefinitely into space, but remain rather close, and when the current ceases, all of the energy, which has been thus stored up in the neighborhood of the conductor, is recovered. Not so, however, the violently formed vortices having complete vacua, which constitute electro-magnetic waves. The energy in this case is thrown out into space and permanently lost.

Let us return to the case of a wire in which a current is just starting. Let us suppose a second wire, parallel to the first and near it. During the formative period of the current, while the circular vortices are being shot out, these rings must cut the second wire on their outward journey. The filament, on meeting the wire, wraps itself around it, reunites its ends on the other side, and continues on as a straight filament. This is indicated in Fig. 3. For an instant, a vortex ring surrounds the wire, but, as we have seen, this instantly rolls itself out into a linear current in the second wire, having a direction opposite to that in the primary wire. The direction of an induced current is, of course, determined by the direction of the current sheet at the point where it first touches the wire. When the current in the primary becomes steady, its ring

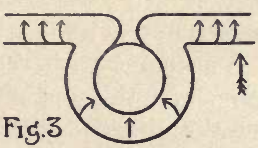

Fig. 3

vortices become stationary, and the induced currents in the secondary wire cease. If the current in the primary now decreases or is broken, the vortex field falls back towards the primary, and such rings as are outside the secondary must cut it on their return journey. In this case the inner edges of the vortices touch the secondary first, and the rotation is such as to shoot the induced current in a forward direction. During the outward excursion the ring system cuts the secondary wire more slowly, while the inward fall is of the nature of a collapse, or a greater number of lines cut the wire in the same interval of time. The electro-motive force of the induced current comes from the rotational energy of the vortex filaments. The total number of lines cutting the wire, outward and back, is, of course, the same, and the same amount of electricity flows in the reverse and direct induced currents. The direct induced current, however, is under a higher pressure, and lasts a shorter time.

The motion between the filament and the secondary wire, need, of course, only be relative. Thus if the vortex field is stationary, and the wire moves through it, the induction effects will be the same. Referring to Fig. 3, if a magnetic line is just above the wire and we send a current through the wire in the direction of the previous induced current, the first vortex ring surrounding the wire will break at the top and become continuous with the magnetic line, as shown in the figure. At this instant the magnetic line is partly bent around the wire, and, since such lines always strive to preserve a minimum length, it will straighten out, thereby pressing together the lines below and separating those above. The lateral pressure will move the wire upward. The direct pressure of the vortex surfaces on the wire is resisted by the pressure of the current in the wire. The vortex cannot enter the wire, and the latter is forced directly upward. Only a single layer of vortices covers the wire at any instant. The

magnetic lines above get below the wire by this process of merging with the surface (current) vortices, and then straighten out below.

If we move the wire downward, a current is induced in the wire. If we send an equal current in the same direction, the wire is moved upward, and we shall have to use the same force in moving the wire downward as that with which it reacts upward.

If we surround the primary wire with a metallic cylinder, then every vortex travelling outward will, on striking its inner surface, unroll itself completely into a linear current travelling backward. The entire vortex will thus have disappeared. As no vortex can escape outside the cylinder, there will be no magnetic field external to it. On breaking the primary current, only those lines which are between the wire and the cylinder are left to collapse. Consequently the "extra" current in the primary will be reduced by the amount of the lines which have been lost in the cylinder, and there will be no direct induced current in the secondary. This shows that electro-magnetic waves cannot penetrate a conductor. The reverse induced current on the inner surface of the cylinder, however, sends out a vortical system of its own, and the electro-magnetic waves which left the primary are thus *reflected* from the secondary. A conductor is therefore impermeable to electro-magnetic waves, but it reflects them. This is precisely what takes place at the reflecting surface of an ordinary mirror. Light, which consists of electro-magnetic waves, cannot penetrate the surface of the quicksilver, but is reflected. The energy of the reflected wave can never equal the energy of the original wave, since a portion of this energy is used up in driving the currents induced in the conductor. Hence conductors are opaque to electro-magnetic waves, while non-conductors transmit them and are therefore transparent. This latter statement must be modified to the following extent. While all non-conductors are trans-

parent to electro-magnetic waves of sufficient length, yet when these waves become exceedingly short and the molecules of a body are comparatively large, so that waves and molecules are not so greatly apart in the *order* of magnitudes, currents are generated inductively in the molecules which send back waves of the same length as the impinging wave. The induced currents are thus able to *resonate* with the frequency of the impinging wave more or less, with the result that the energy of the wave is used up in a comparatively short thickness of the dielectric. In such a case little of the energy gets through, and a small portion is reflected. Owing to this molecular inductive action, a portion of very short electro-magnetic waves is always reflected, even in the most transparent media. Thus glass, which easily transmits light, nevertheless reflects a small portion of it.

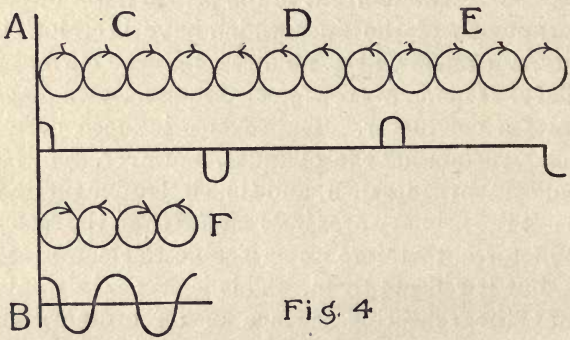

Fig. 4

Let us suppose that a vertical wire, AB, is traversed by alternating currents. A series of vortex rings will be driven out, one set of them rotating one way, the next set rotating in the opposite direction. Fig. 4 represents a section through the wire showing three trains of vortices, C, D, E, consisting of four vortices in each train. C rotates to the right, D to the left, and E to the right again. We shall suppose the alternations to be very rapid—some millions

in a second. Of course, it is possible to detect the mere passage of such a train of electro-magnetic waves, and signals could be given by sending out such a train, then stopping, and then sending again. And in fact this is done in wireless telegraphy. The dot and dash messages of the wireless codes are signaled by sending short trains and long trains with stops in between. But it has not yet been possible to construct an instrument which could distinguish between the alternations in a continuous train.

Let us suppose such trains of vortices striking at some distant point upon an instrument capable in some way of distinguishing between the alternations. Let us examine in what way the differentiation of such whirls could possibly be effected. Considering a single vortex, it would appear that, since the upper and lower edges arrive simultaneously at any point, and are moving in opposite directions, any effect which these motions might separately produce, would certainly nullify each other. And considering the front and back edges, since the contiguous edges of the neighboring vortices move in opposite directions and are in close juxtaposition, thus arriving at practically the same instant, it would seem hardly possible that any instrument could distinguish between individuals in a train of vortices rotating all the same way. It might detect the front of a train and the rear, but during the passage of the train no indication could be given.

However, at the junctions of the oppositely rotating trains, the motion of the rear edge of the last vortex coincides with the motion of the front edge of the next following vortex. Hence at these dividing lines there will be a doubled upward motion followed by a doubled downward motion, and so on alternately. It would seem possible that such a simulated or quasi transverse vibration might be detected. Considering only these up and down components of the motion, which are the only ones that could possibly be detected, it is evident that they would

form a curve like that represented under the trains *C*, *D*, *E*.

Let us suppose that we make out alternations still more rapid—billions of them in a second. It is impossible to get such frequencies in conductors, or oscillators of finite dimensions, but using an atom as an oscillator or by making an atom vibrate backward and forward, it is possible to obtain such frequencies, and the vortex trains sent out by such an alternating current would be reversed with this order of frequency. Such vibrations would be something like 5×10^{14} times a second, or the same as the frequency of light vibrations. These vortices are shot out with a velocity of 3×10^{10} centimetres per second, which is the velocity of light, and all electro-magnetic waves An atom vibrating with such frequencies sends out trains in which every vortex is preceded and followed by one rotating in an opposite direction, or every train of the same kind consists of only one vortex. This is represented in *F*, Fig. 4.

Taking account only of the up and down motions, which are the only components of the vortical motion which could possibly be detected, we see that this motion is represented by the curve under *F*. It is a simple sine wave, a complete wave length being equal to two vortex diameters. We pointed out that the only hope of detecting such alternating trains was that there might be some instrument capable of being affected by the up and down, or transverse components of the motion, which, though acting in opposite directions, nevertheless do not act together at the same instant but are separated by a minute interval of time. Now there *is* such an instrument, and it is competent to detect the transverse components of electro-magnetic waves, provided the alternations are of the requisite frequency. This instrument is the eye.

It has previously been supposed that, in transmitting light waves, the motion of the ether was purely trans-

versal. But it is impossible for a fluid medium to execute such motions, and it cannot transmit waves with transverse vibrations. This is a property of solids alone which are capable of undergoing shearing strains. Hence the many incongruous and impossible descriptions of the ether. It was said to be a fluid with the properties of a solid, a jelly, a "kind of glorified pitch," and what not. Of course nobody ever understood these descriptions, and especially not the learned expounders themselves. It has done harm to many, in that they have been led to pretend to understand what was impossible of comprehension, and it has outraged reason which should be kept sacred.

We have stated that electricity is the ether and the ether is electricity—they are synonymous. To any one who is not convinced after reading the foregoing pages, the argument may be put in a more formal way. We saw that we were able to produce a current in a conductor by simply touching a vortex filament, or line of magnetic force. The question arises "Where did the electricity in the the conductor come from?" Electricity is a material substance of some kind—it is *something*. Now anything that exists, that is material, cannot be manufactured from nothing, neither can it be destroyed. The electricity which we have brought into the conductor must have existed somewhere else before. It did not exist in the conductor, for a careful examination showed not a trace of electricity on it or in it. It did exist then, in the magnetic line. But a magnetic line is simply ether in motion. This can be easily proved, and in fact nobody doubts it, although it has not heretofore been recognized that a magnetic line is simply a vortex filament. Consequently electricity can be nothing else than the ether. The present mathematical investigation showing that such an assumption leads necessarily to all the observed phenomena, and conversely that such phenomena can only

be produced by such a mechanism, lends cumulative evidence that is irresistable.

Certain metals—iron, nickel and cobalt—possess a curious property in that their molecules are capable of being set in rotation about an axis and of continuing this rotation indefinitely. If we place such a body in a magnetic field, the axes of these molecules are dragged into the magnetic lines and begin rotating with the velocity of the vortex. They reinforce thus greatly the whirl and are said to have a very high "permeability" for magnetic lines. The theory of Ampere was that in a magnet, little currents were continually circulating around its molecules, and that the axes of these currents were all turned in the same direction. It is true that there are currents circulating about the magnetic lines, but these currents are not limited to the molecules, but are continuous current sheets forming a vortex. Further the molecules are not stationary, but are rotating with the vortex. By their momentum they reinforce the whirl and keep up the rotation even when the magnetic field is withdrawn. We might consider these molecules as an assemblage of little fans, whirling the ether around and along the magnetic lines. It is clear why the energy of the whirls is so greatly increased, since on the original magnetic field, the independent field of the molecules is superposed.

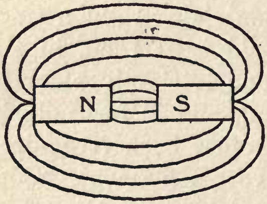

Fig. 5

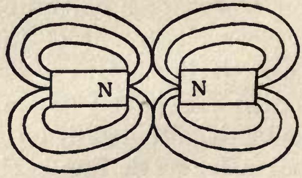

Fig. 5 represents, on the left, two magnets with opposite poles next to each other. The vortices traverse both magnets with the intervening air gap and then close round

on the outside. Where the magnets are nearest the vortices are crowded together and are of greater cross section. When isolated the number of lines in the two magnets is twice as great, but when in this position, they join hands, a positive end grasping a negative end, and though the number of lines is halved, the energy is greatly increased in the air gap. The outer lines are farther apart and much more tenuous. The lines repel each other laterally with considerable force (centrifugal), but are pressed together by the general etheric pressure, thus assuming a pattern of equilibrium. They always tend to shorten and it is evident that the attraction which the two magnets exert on each other is due to their being pressed together by the general etheric pressure. In the right hand of Fig. 5 are two magnets with similar poles opposed. Similar lines do not join hands, since if two such lines met head on, they would be rotating in opposite directions. They turn away and are crowded back, since all such lines repel each other laterally. This results in an elastic distortion of the original patterns, and since these patterns always strive to regain their original symmetrical shape, the magnets are pressed apart.

The attraction is due to the general etheric pressure striving to close up the partial vacua in the tubes, while the repulsion is due to the lateral repulsion of the lines striving to overcome the distortion of their original patterns.

STATIC ELECTRICITY

Ether is a condensed state—of higher density than the normal ether—is a differentiated condition which we call positive ether or positive electricity. Likewise ether in a rarefied condition is negative ether or negative electricity. While ether in motion constitutes an electric current, if that be not a tautological statement, positive and negative ether at rest are what is known as static electricity.

We have seen that gross matter at the surfaces of solids and liquids is in a differentiated condition. The molecules here are crowded together and the matter is much denser than in the interior. The surface is in a state of strain, having a "surface tension,"—a condition which gradually falls off towards the interior. We have also seen that gross matter exerts an attraction or repulsion on all other matter, according as that matter is denser or less dense than the ether. This action is especially strong at infinitesimal, or small, distances, rapidly falling off, so that at a very small distance from a molecule it is practically negligible. A charge of condensed ether will therefore be attracted and held by a material surface, while a charge of negative ether will be repelled from such a surface. In the interior of a conductor, since such actions are from all directions, the ether cannot remain in a state of strain, but must be at the normal density throughout. A charge of positive or negative ether placed at some point in the interior of a conductor would therefore move to the surface, where it would be held. Even if it were on a surface presenting a concavity, it

would represent here a surface tension τ, which, by Laplace's formula, would give rise to a normal pressure, $p_n = \frac{2\tau}{R}$, where R is the radius of curvature of the surface. Since this normal pressure is directed towards the interior, the charge could not maintain its position, but would move through the conductor to the convex side to a position of equilibrium, where the normal pressures, directed outward, would be balanced by the equal and *opposite* attractions of the surface.

We shall assume that in a conductor the atoms have contact with each other at some point, so that a continuous surface is furnished over which the charge can move. In a non-conductor, the atoms (molecules) not being in contact, charges may be held by each molecule, since this ether is not able to move away, and may be held locally in a state of strain.

A positive charge on a surface is held by the attraction of the surface acting on the denser ether. Now this attraction is proportional to the density of the ether, and since all the layers apply their "weight" cumulatively to all the under layers, the lower-most layers will be denser and more strongly attracted. We can consider the surface to be covered by an atmosphere of dense ether which decreases in density progressively upward, until at a certain short limit, which is the height of the atmosphere, the pressure, or density, becomes equal to the normal pressure of the ether. The case is analogous to the atmosphere of the earth, which decreases in density logarithmically upward, until it acquires the density of the ether. (See "The Atmosphere," by the author.)

When a negative charge is applied to a surface, the gross matter repels it, and its density increases upward, until at a short distance—the height of the charge atmosphere—the density becomes equal to the normal

ether density. The previous case is reversed, and we have an inverted atmosphere. The analogous condition for the earth would be that it were imbedded in an infinite ocean of air having the present density at the surface, and that the earth should repel the air. In this case, the earth would have an inverted atmosphere. For both positive and negative charges, we shall consider the pressure (density) at the surface, as the pressure, or potential, of the charge. Actually, every charge contains all pressures in its atmosphere from the normal ether pressure up to (or down to) the maximum (or minimum) pressure of the charge.

If we continue to introduce new masses of ether below the superincumbent layers, we shall have to do work. We may do this work by forcing ether onto the surface against the maximum pressure, or we may condense the ether first and then transfer it to the surface. As we continue to add thus new masses (charges) of ether, the pressure (tension) of the lowest layer will continue to rise. This cannot go on indefinitely, since the pressure of the lowest layer will finally reach a point where it is equal to the attracting or holding force of the surface matter. When this happens the lowest layer bursts or breaks away, leaving the surface bare of any charge. From Laplace's formula, $p_n = \frac{2\tau}{R}$, it is evident that the bursting pressure will be reached at a very low point on a sharply convex surface, where the radius of curvature is small.

In the same way, if we keep introducing negative ether onto the surface, below the other layers, a point will be reached where the repulsion will be unable to withstand the increasing external pressure, and the system will break down. Since the outer normal ether pressure acts *with* (in the same direction as) the attraction on a positive charge, and *against* the repulsion on a negative charge,

it is evident that a considerably higher pressure can be reached in the layer next to the surface in a positive charge, than the corresponding negative pressure in a negative charge. Or the breaking negative pressure of a negative charge is considerably below the corresponding positive pressure for a positive charge. It has long been known that a negative charge breaks down under a less pressure than a positive charge. For a similar reason a negative charge is dissipated more quickly than a positive charge of the same potential.

Let us suppose a spherical conductor with a positive charge, surrounded by a concentric metal spherical shell, with a non-conducting space separating them. The longitudinal positive waves given off by the surface of the conductor cause the successive layers of the charge to pulsate. We may consider these layers to pulsate synchronously. The influence of the charge may be to polarize the vibrations of the surface molecules, so that they all vibrate in the same direction and synchronously. As the compressed halves of the longitudinal waves emerge from the denser medium of the charge into the free ether, they become transformed into expansional halves, and vice versa, the expansional halves of the original waves, on emerging into the free ether become transformed into compressional halves. The character of the waves after passing through the charge therefore becomes reversed, and the charge radiates from its surface negative waves. Or, considering a positive charge to be contracting and expanding, it is evident that the contraction, or backward movement, must result in increased condensation, while the expansion, or forward movement, must result in a rarefaction. It is inevitable, therefore, that the waves emanating from its surface must have their condensed halves moving towards the disturbing source, and their expanded halves moving away from it. The reverse is the case for negative charges. Hence positive

charges radiate negative waves and negative charges radiate positive waves.

Now as the waves emanating from the positive charge strike the inner surface of the enveloping shell, they apply to it in quick succession, positive and negative charges, viz., their condensed and expanded portions. If the central positive charge were removed, and we should apply successively positive and negative charges to the inner surface of the shell, they would immediately flow to the outer surface and there neutralize each other. But with the central positive charge in position, the negative charges are held (attracted) and cannot flow to the outer surface. The result is that as the waves deposit their charges, they become separated, the positive charges appearing on the outer surface and the negative charges accumulating on the inner surface. It may appear unintelligible why the two charges do not neutralize each other on the inner surface, but experiment shows that if we have a bound (induced) charge on one side of a conductor and no charge on the other side (removed by earthing), we can apply an opposite charge to the conductor which will reside on the previously uncharged side, and it makes no difference to which side we apply this charge. In the case of our shell, the explanation probably is that the waves are simply transmitted through the bound negative charge as through a rarer medium, and appear intact on the outside.

We have said that the total energy of a unit mass of ether is proportional to its absolute pressure. The ether, therefore, represents a tremendous amount of energy. It conserves this energy from the fact that its total body is at a uniform pressure and there is no other source of higher or lower potential from which it may gain or lose energy. Where this original energy came from, and by what mechanism it manifests itself, i.e., by what form of motion its pressure is exercised, has, as yet, been the subject of the barest surmise.

We shall assume that the rate of energy outflow, or the rate of the dissipation of the energy of a body, is proportional to its potential or pressure. Two bodies radiate their energy to each other, but if they are at the same potential, the gain is equal to the loss and their potentials remain unchanged. A charge of ether, having a greater potential than the normal ether, must dissipate its energy at a rate proportional to the excess of its pressure above that of the general ether. Practically it is found that a charge of electricity is dissipated at a rate proportional to its pressure above the normal, just as a hot body cools at a rate proportional to its temperature above its surroundings (Newton's law*). Temperature is the analogue of a potential or it can be considered a heat potential. Thus a positive charge continually loses energy, and a negative charge continually gains energy. We have every reason to believe that the energy of a charge is dissipated through longitudinal waves.

Stephan has found that for very high temperatures (such as that of the sun) the rate of radiation is best represented by the fourth power of the absolute temperature. We have to do here with electro-magnetic waves (heat), and the ratio of the output of energy in unit time to the potential of the source does not remain constant, as with longitudinal waves, but increases progressively as the potential rises.

The quantity, Q, or mass of ether in a charge is proportional to its volume by its pressure, p, above the normal. The volume of the charge is Sh, where S is its surface and h is the height of the charge. Since h is always small and does not vary appreciably we can assume the volume to be sensibly proportional to the surface, and therefore $Q = pS$. Let E be the energy in a wave given off by unit surface of a charge. Then $\frac{E}{t}$, where t is the time of a complete wave vibration, is the output of energy

* We exclude, of course, leakage by conduction and convection.

per unit surface, per unit time. This is proportional to the pressure, or $\frac{E}{t} = kp = k\frac{Q}{S}$. Or $\frac{ES}{t} = kQ$. Hence the rate at which the energy flows across an enveloping surface is proportional to the charge.

The radiations from our three charges are all directed away from their respective surfaces, so that the external positive charge can in no way influence the internal charges. If a charge were outside and wholly detached, it would merely induce charges on the outer surface of the shell and therefore could in no way influence the internal charges. This is a general principle, viz., that no external charge can in any way influence, or exert a force upon, an internal charge. But a charge placed in the interior of a hollow conductor can influence outside charges through the induced charge which appears on the outer surface. We shall hereafter not consider this external charge, as we are to deal only with the internal charges. Whether we remove it by earthing, or not, will make no difference.

We have said that the waves radiated by the central charge apply successively positive and negative charges to the outer and inner surfaces of our shell. But this cannot go on indefinitely. When the outflow of energy from the inner charge is equal to that which it gains from the central charge, its energy can no longer increase, but remains stationary. Since the total energy flowing into the inner charge is proportional to Q, the central charge, and the total energy flowing out of the inner charge is proportional to Q^1, its own charge, when $Q = Q^1$ there can be no further increase, and the induced charges on the shell become, practically instantaneously, equal to the central charge, and remain so.

We have seen that the attraction of longitudinal waves on a body having a density different from that of the ether

is $\frac{E}{t} \cdot \frac{D^1 - D}{D^1} S$, where E is the energy in a unit cross section of the wave, and D^1, and S, are the density and surface respectively of the body acted upon. The central charge will therefore attract the inner charge with a force proportional to $\frac{ES_1}{t} \cdot \frac{D_2 - D}{D_2} S_2$, where S_1, is the surface of the central charge, and S_2 and D_2, the surface and density of the inner charge. But we have seen that we can write $\frac{ES_1}{t} = Q$, and since the density of a charge is proportional to its absolute pressure above zero, we can write the attractional force, $Q \cdot \frac{P_2 - P}{P_2} S_2$. Calling p_1, and p_2, the pressures of the two charges above and below the normal pressure, this becomes $Q \frac{p_2 S_2}{P_2}$. But $p_2 S_2 = Q$, and the attractive force is proportional to $\frac{Q^2}{P_2}$. Likewise we find that the attraction of the inner charge is $\frac{Q^2}{P_1}$. Now the fraction $\frac{P_1 - P}{P_1}$ is sensibly the same as $\frac{P_1 - P}{P}$, since they differ only by $\frac{(P_1 - P)^2}{P_1 P}$, and $(P_1 - P)^2$ is very small and $P_1 P$ is relatively very large. Hence, although the attraction of the central charge on the inner charge is very slightly greater than vice versa, yet they are sensibly equal, and the mutual attraction is proportional to Q^2.

If two charges are on non-conductors (such as pith balls), where inductive action is not possible, and one body does not surround the other, but they are small

compared with their distance apart, the mutual attraction becomes proportional to $\frac{QQ^1}{r^2}$, since the energy per unit surface falls off inversely as the square of the distance. This was discovered by Coulomb experimentally, and is known as Coulomb's law.

If the medium between the two charges becomes denser, so that the velocity of wave proportion becomes less, or t becomes greater, or, what is the same thing, the quantity of energy flowing in unit time becomes less, the attraction between the charges becomes less, since the force is proportional to $\frac{E}{t} S \cdot Q^1$, S being the surface of the radiating body.

Two bodies charged with opposite charges of electricity attract each other because the charges exert attractions on each other. The charges cannot leave the bodies since they are held by the surface attraction and the bodies are forced to follow the movements of the charges. The atoms, of course, attract each other, but since this action is upon discrete specks of surface, while that of the charges is upon large continuous surfaces, the atomic attraction is insensible, while the electrical attraction is comparatively very large, and very appreciable.

Returning to our shell, let p be the pressure which the central charge had before it was introduced into the hollow conductor. Then, at that time, $Q = kpS$, or, for a given pressure, the *capacity* was proportional to the surface, k being the proportionality factor. Inside the conductor, the pressure becomes $p—Q^2$, since it is lessened by the amount of the mutual attraction of the charges. Since the charge must remain the same, we have

$$Q = kpS = k^1 (p—Q^2) S,$$

where k^1 is a new proportionality factor of capacity.

$\frac{k^1}{k} = \frac{p}{p-Q_2}$. The new specific capacity factor is, therefore, very much greater than the old one, or it will be possible to load the same surface with a much greater quantity of electricity before reaching the same potential. Hence, by allowing the central surface to be in communication with some source of electricity, kept at a constant potential, it will be possible, by the aid of the attraction of the inner induced charge, to load it with an enormously greater quantity of electricity than if it were isolated.

If we fill the space between the two charges with some denser dielectric, which reduces the velocity of wave propagation, we shall get a new factor of specific induction. The mutual attraction of the two charges is proportional to $\frac{Q^2}{t^1}$, becoming less as t^1 becomes greater. The attraction exercised by a material surface on a charge is proportional to the pressure of the charge. Let g be this attraction per unit of surface. Then the surface attraction on the charge will be gp, and $gp - \frac{Q^2}{t_1} = p$, or $Q^2 = p(g-1)t^1$.

If we keep the central charge connected with a source of electricity at constant potential, p, the electricity flowing in will increase the charge, but as the quantity increases, the inner induced charge also increases, and their mutual attraction, tending to lower the pressure, increases as the square of the quantities. Q^2 is proportional to t^1. Hence as the velocity of wave propagation in the medium decreases, the load of electricity at a given potential becomes greater. If we take the ratio of the quantity of electricity with which we must load the central conductor to bring it up to a certain potential when a dense dielectric is used, to the quantity necessary to bring it to the same potential when only ether intervenes, we shall obtain the specific

inductive factor of the dielectric. This quantity is usually designated by K, and is called the specific inductive capacity.

$K = \sqrt{\frac{t_1}{t}} = \sqrt{\frac{V}{V_1}}$, where t^1 and V^1 are the time of a wave vibration and its velocity in the dielectric, and t and V are the corresponding quantities in the ether. K is not constant for the same dielectric, but varies with its temperature and from other circumstances which we shall discuss later. Assuming K to be determined for a given temperature, and in a simple induction, i.e., one without complicating factors, the attraction between two opposite charges would be proportional to $\frac{QQ^1}{K^2r^2}$, and the specific inductive capacity of the dielectric would be $K = \sqrt{\frac{V}{V^1}}$. The mutual attraction between the central and inner charges of our shell varies as $\frac{1}{K^2}$, or as the velocity of wave propagation in the medium separating them, but if the central charge be kept in communication with a source at constant potential, the attraction will not vary, no matter how the dielectric varies, for $\frac{Q^2}{t^1} = p\ (g-1)$, which shows that the attraction remains constant.

We have hitherto considered the action of the dielectric as simply that of transmitting longitudinal waves. But if we place a solid dielectric between the two plates of a condenser the molecules will become loaded individually by induction. The waves will deposit positive charges on one side and equal negative charges on the other.

They will become polarized in the direction of the waves. Now in a single conductor, as soon as the inducing charge is removed, the equal and opposite induced charges immediately reunite, but in a nonconductor, the molecules have their charges aligned so that the molecule next ahead turns an opposite charge to that on the molecule next behind. These opposite charges attract and hold each other, so that when the electric field is removed, the charges do not reunite, but maintain their positions. They are now an independent source of energy and send out waves in the direction in which they are aligned. The case is analogous to that of a magnet, which, even after the polarizing source is removed, maintains its independent field in the same direction. Hence the induced charges in a condenser, which, for a given potential, are greater as the wave velocity decreases, are still further increased by this action in the dielectric. The molecules have stored up an independent source of energy which is superadded to that of the original field.

If we place a plate of mica in a strong electric field (between the plates of a condenser), the mutual attraction of the induced charges on its molecules puts it in a state of strain. It is as if the plate were pressed between the jaws of a vise. If the pressure becomes too great, some of the molecules, along a line of weakest resistance are forced away from their positions of equilibrium and a fracture results. If we peel off leaves from the plate, we shall find that throughout there are always charges of one kind on one side and charges of the opposite kind on the other, no matter how thin the leaves are. This action is not so strongly marked in liquids, and of course when the electric field is removed, no polarization remains. A solid dielectric so internally polarized has been called by Heaviside an *Electret*, from its analogy to a magnet. The strain in a transparent dielectric like glass is easily demonstrated by a ray of light. Since it is compressed in the

direction of the field, it will behave like a uniaxial crystal, subjecting light to a double refraction, and transmitting an ordinary ray and an extraordinary ray.

We have seen that the specific inductive capacity of a substance varies inversely as the square root of the velocity of wave propagation in it, or $K = \sqrt{\frac{V}{V^1}}$. This is for a simple inductive action. But, for solid and liquid dielectrics, this is complicated by the electret action, and the induction becomes a more complicated function. It is further complicated by the temperature of the substance since the condition of the molecules as to motion must markedly affect all inductive action. It would therefore be difficult to derive a formula connecting all these variables. Even experimentally it is extremely difficult to determine the inductive factor with reasonable accuracy. Various investigators give rather different determinations for various substances. Thus we have

For Shellac	Faraday	1.55
	Thornton	2.49
	Everett	2.00
For Sulphur	Thornton	4.03
	Ganot	4.73
	Everett	2.24
For Resin	Thornton	3.09
	Ganot	2.55
	Everett	1.77
For Glass	Everett	1.75
	Thornton	6 to 10

According to Maxwell's theory $K = \frac{V^2}{V^{12}}$. This is known as Maxwell's law. Since $\frac{V}{V^1}$ is the index of refraction of a substance for longitudinal waves, $K = n^2$, where n is the

index of refraction. We have found that in a simple (uncomplicated) induction, $K = \sqrt{n}.$ A few substances have been found which conform to Maxwell's law more or less, but *"Exceptions are much more numerous than accordances." Likewise it is possible to select a list which conforms approximately to the formula $K = \sqrt{n},$ but neither of these formulæ represent all the conditions, and neither can be considered a *law*.

When two different substances are rubbed together, the vibrations of the molecules on the opposing surfaces become polarized and are directed across the junction. Waves are set up, which according to the relative conditions existing in the two kinds of molecules, are in one direction or the other. Simple contact is sufficient to set up such waves. Thus when zinc and copper are brought together, positive waves flow across the junction from the zinc to the copper. These waves deposit charges, and the wave force keeps the negative charges at the copper end and the positive charges at the zinc end. When glass and resin are rubbed together, the glass acquires a positive charge; the resin a negative charge. In a circuit of different metals such waves are set up at the junctions, but their algebraic sum is zero, and therefore no current flows. However, if the wave energy at one junction is differentiated from the rest by heating or cooling, a feeble current ensues.

A charged spherical body sends out its waves radially. A small charge in its neighborhood will be attracted or repelled along a radial line, if no other charged body be near. If another charged body be near, this likewise will radiate waves in straight lines from its surface, the radiations from both bodies taking place exactly the same as if the other were not present, providing the charges are on nonconductors, and their distribution cannot be altered inductively.

* Ganot's Physics.

If we explore the combined field with a small charge, it will move in a path, the direction of which at any point, is the resultant of the forces arising from the two independent fields. If the two bodies are oppositely charged, the path will be a curved line leading from a positive charge on the surface of one body to an equal negative charge on a certain point of the other body. We could map out the different curved paths which such a small charge would follow starting from different points of one surface, and these paths would represent the combined field of force between the two bodies. These different paths are called lines of electric force. They have however no actual existence, but are merely mathematical figments. What actually exists are the wave trains being given off by each charge, and these pursue their course absolutely uninfluenced by one another. This is not the case with magnetic lines, which are physical realities—actual linear vortices in the ether—and the presence of other lines influences their condition greatly, leading to their merging together or repelling each other.

The case of a conductor offers a peculiar situation as regards the specific inductive factor, K. It has been considered that K for a conductor must be regarded as infinite, in which case the velocity of wave propagation would be zero. This would have to be interpreted that no longitudinal waves can exist in such a medium. We might perhaps equally well consider K here as zero, or the wave velocity infinite. The fact appears to be that there is really no such thing as an inductive coefficient for a conductor, and we might as well speak of the temperature of a charge of electricity.

Starting with the hypothesis that static charges of electricity were simply differentiated portions of the ether, denser or less dense than the general ether; that such charges continually give off longitudinal waves of two different kinds, according as they are positive or negative, positive charges giving off negative waves and negative charges giving off positive waves; and that all electrical actions at a distance (attractions and repulsions) were

due to these waves; we have been able to deduce theoretically all known facts regarding electrical actions. The steps in the reasoning are

1. Action at a distance can only be effected through a medium. 2. That medium is the ether. 3. Such action can only be effected by some kind of motion in the medium, and this motion must be imparted by the acting body. A *dead* body cannot act, although it may be acted upon. So far we are upon uncontrovertible ground. 4. Longitudinal waves necessarily cause such actions (attractions and repulsions) and, excluding magnetic actions which have no place in electrical actions, they are the only kind of motion in the medium capable of effecting these actions.

An exception may be taken to No. 4. It may be said that, granted longitudinal waves can produce such actions, there may possibly be some other kind of motion, which we have not thought of, capable of producing exactly the same effects. The probability of any other kind of motion producing the many diverse and complicated phenomena of electricity; of the exact agreement of all its effects with those of longitudinal waves, though itself different, is infinitesimal.

ELECTRO-CHEMISTRY

In Fig. 6 we have a cell containing dilute sulphuric acid in which zinc and copper plates are immersed. To each plate is connected a wire of the same material.

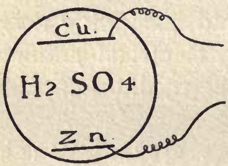

Fig. 6

When the wires are not in contact no action of any kind takes place, but when the wires touch, at the surface of contact longitudinal waves are set up, the direction of which is determined by the nature of the two kinds of molecules. When zinc and copper are in contact the direction of the waves is from the zinc to the copper, so that a positive charge is produced and held in the zinc end, while a negative charge is applied to and held on the copper plate. If the positive charge on the zinc plate could flow through the liquid to the copper plate, a current would flow and there would be an immediate equalization of potential. But the molecules of liquids are not in contact and a current, therefore, cannot flow through a liquid. They are absolute nonconductors. Under an enormous pressure, a path could be broken through the molecules by a charge, just as it is possible to break down any dielectric, but this is not conduction. Our plates oppositely charged therefore form a condenser, of which the liquid is the dielectric. The liquid, in fact, becomes a fluid electret. It is under a state of strain, and its molecules arrange themselves with their negative charges pointing towards the zinc, and their positive charges pointing towards the copper.

Now the atoms of a chemical compound are held together as molecules by the action of equal and opposite charges on the various atoms. Thus, in *HCl*, there is a positive charge on the hydrogen atom, and an equal negative charge on the chlorine atom. The atoms never come into actual contact, but are held together by the mutual attraction of their two opposite charges. It has been supposed that they revolve about their common inertianal centre, just as two heavenly bodies do, the centrifugal force balancing the attractional force, but this is a matter which does not concern us here. The important point is that what is known as chemical affinity between atoms is due simply to the attraction of equal and opposite charges on the atoms or radicles.

But to return to our liquid electret. The molecule of sulphuric acid is composed of two atoms of hydrogen, each with a definite charge of positive electricity, and a radicle SO_4 which holds a negative charge equal to the positive charges on the hydrogen atoms, or equal to double the charge on a single hydrogen atom. In the electric field between the two plates the atoms arrange themselves in the direction of the strain (wave) lines—the hydrogen atoms being nearest to the copper, and the radicle SO_4 nearest the zinc. The molecules of the liquid do not come into actual contact with the plates. Hence, in an unpolarized condition, no charge exists on the plates acquired either inductively or by direct application. But in a polarized condition the hydrogen atoms next to the copper plate all face towards this plate, and the SO_4 radicles next to the zinc plate all face towards this plate. Extra charges are thus induced on the two plates—the hydrogen atoms inducing an equal charge of negative electricity on the copper, while the SO_4 radicles induce an equal charge of positive electricity on the zinc. The result is that the molecules immediately next to the two plates become torn apart, the positive halves being urged

in one direction, while the negative halves are urged in the other. These two oppositely charged parts of a molecule are called ions. The negative ions (SO_4) are urged towards the zinc, while the positive ions (H) are repelled from the zinc and urged towards the copper. Thus there is a procession of hydrogen ions towards the copper, and a procession of SO_4 ions towards the zinc. This is called the "Migration of the ions." As soon as the two hydrogen atoms are detached from the molecules, they mutually repel each other, while the SO_4 radicle remains intact with its double charge. This double negative charge is able to detach an atom of zinc which has, of course, an equal positive charge, and thus a new molecule of $ZnSO_4$ is formed. The hydrogen atoms with their single charge are unable to detach an atom of copper, and being drawn into actual contact give up their charges to the copper. The action may be summed up as follows: The hydrogen atoms which previously held positive charges and were bound in an H_2S_4O molecule, are now isolated and without charge. The zinc atoms on the surface, which previously held only a weak charge, though sufficient to polarize the field, have now acquired a strong positive charge, viz., that of which the hydrogen atoms have been deprived, and by virtue of the acquired charge are now the positive halves of a new molecule, $ZnSO_4$. The transference of the positive charges from the hydrogen atoms to the zinc atoms has been effected through the connecting wire. A current has flowed from the copper to the zinc. The charges produced by the contact of the wires were weak. They play little part in the process, except by setting up the original field and determining in which direction the action shall take place. The principal part is played by the strong induced forces. The mutual attraction between the double charges on the SO_4 radicles and the double charges on the zinc atoms, which was proportional to $4Q^2$, was sufficient to detach

the zinc atoms, while the mutual attraction between the charges on the hydrogen atoms and on the copper atoms, which was proportional to Q^2, was insufficient to detach a copper atom. Otherwise stated, the chemical affinity between Zn and SO_4 is four times greater than that between Cu and H. Certain atoms are capable of taking only a single definite charge of electricity. Other atoms may take double or three times this minimum amount, but it is always an exact multiple of the minimum amount. Atoms taking only the minimum charge are called univalent; atoms taking twice this amount, bivalent, and so on. This is perhaps because univalent atoms all have the same maximum capacity. We may suppose atoms of a higher valency to have a greater maximum capacity. Thus a bivalent atom, or one capable of holding two univalent atoms, is able to support two minimum charges, each charge holding one of the univalent atoms. Since the attraction between atoms is always inductive, their charges in a molecule must be equal and opposite. In every case the algebraic sum of the charges in a molecule must always be zero.

While the univalent charge must be regarded as the saturation charge for the atom, beyond which it cannot be loaded, the charge on an atom of higher valency may be far from the saturation point. Thus in $HgCl$, Hg has only the minimum charge, and is not saturated, for it easily holds twice this amount in the compound $HgCl_2$. In our previous experiment with the galvanic cell, in which we converted a molecule of H_2SO_4 into a molecule of $ZnSO_4$ by transferring the positive charges on the hydrogen to the zinc atom, we have done work. For the current which flowed in the wire heated the wire, thereby expending energy. Hence the electrical energy in the $ZnSO_4$ molecule must be less than that in the H_2SO_4 molecule. The quantity of electricity is the same, but the pressure must be less. We have seen that the mutual attraction of two

charges lowers their pressure. The attraction on the hydrogen charges lowers their pressure by an amount proportional to $2Q^2$, while the attraction on the zinc charge lowers its pressure by double this amount, or proportionally to $4Q^2$. The charges on the hydrogen atoms, therefore, have forced their way through the resistance of the wire by sacrificing a part of their pressure.

If we place two platinum electrodes in a cell containing H_2O, and give one electrode a positive charge and the other a negative charge by attaching them to some electro-motive source, such as a galvanic cell, we have again our liquid condenser, or electret. Since the hydrogen atoms are positively charged and the oxygen atoms negatively charged, they will stretch themselves along the strain lines, the oxygen atoms towards the positive electrode, the hydrogen atoms towards the negative electrode. Immediately at the surfaces of the electrodes, the molecules will be torn apart, and the hydrogen atoms will give up their charges to the negative electrode, while the oxygen atoms give up their charges to the positive electrode. The procession of ions begins, and each atom will deposit its charge as if it were a living carrier with a bucketful of a certain definite quantity of electricity. The buckets of the oxygen carriers hold exactly twice as much as those of the hydrogen carriers, but as there are twice as many of the latter as of the former, the total quantities transferred are equal for both sides. Each carrier makes only a single journey. When the atom has deposited its measure it is discharged and is no longer subject to the influence of the field.

Suppose we are using the zinc-copper-acid cell for the electro-motive source. It will seem as if a current were flowing, but actually there is no flow. The two cells are absolute nonconductors, breaking the metallic circuit at two places. However, in both cells, the carriers are busy ferrying over the electricity, we might say, from one

bank to the other. In the galvanic cell, the ferrymen are the hydrogen atoms and the SO_4 radicles, while in the water cell, the ferrymen are the H and O atoms. It is as if a fluid were being pumped along in a hose, but at two places the hose is broken. The only way to overcome these obstacles is to form two bucket lines, and at each break a line of buckets is seen forwarding the fluid with full buckets in one direction while a line of empty buckets is coming back in the other direction. The number of buckets used measures very accurately the amount of fluid transferred.

In the water cell, we have decomposed the water molecules, and this process of tearing apart molecules is called *electrolysis*. The oxygen is deposited at the positive electrode and the hydrogen at the negative electrode, without any charges, whereas they previously had equal and opposite charges, and by virtue of these charges were able to combine into molecules forming water. The galvanic cell has done work, while the water cell has had work done upon it. The amount of current, or quantity of ether, necessary to transfer given amounts of electrolytes is readily computed, and vice versa, the amount of electrolytes deposited gives us a very accurate measure of the amount of current used. It is evident that twice the amount of current will be necessary to deposit a given amount of Hg from the compound $HgCl_2$, as from the compound $HgCl$.

Grotthüss (in 1805) framed a hypothesis that the molecules of an electrolyte aligned themselves along the strain lines, their positive and negative sides being directed towards the opposite electrodes. This they undoubtedly do. He further supposed that under a sufficiently powerful current in the liquid (at that time it was supposed that a current could flow through a liquid) the molecules were disrupted throughout the entire line, the positive half of one uniting immediately with the adjacent negative half

of the next one, and that at the extreme ends only a single ununited component was left. Clausius very properly objected that a very great force must be required to disrupt all the molecules simultaneously, and that below a certain minimum strength of current, no decomposition could occur. Now the action of even the weakest fields can produce some decomposition. When the molecules are facing promiscuously, those next to the electrodes can exert no inductive action upon them, but if a field is sufficient to polarize at least some of them, then the inductive action of those molecules directed towards the surface acting jointly, is appreciable, and decomposition results. The actual disruption of the molecules takes place only directly at the surfaces of the electrodes, and not in other parts of the line.

According to the modern theory, the molecules of a compound in solution are always more or less dissociated, their ions continually separating and recombining. The theory further assumes that electrolysis is carried on solely by such dissociated ions, and that if no dissociated ions were originally present, electrolysis would be impossible. But electrolysis can be carried on equally well with or without free ions in the original solution. Even if free ions should be present previously to applying the electric field, they will carry on only a part of the process, for there must also be a disruption by induction of the extreme molecules next to the electrodes. Since in framing any explanation it is wise to postulate no more conditions than are absolutely necessary, and since the assumption of previously existing free ions is unnecessary for the explanation of electrolysis, we shall not consider it in the present discussion. Whether under other circumstances and in connection with other phenomena, it is necessary to assume such dissociation as a general condition of all solutions, is a question which does not concern us here. It may be remarked that the theory was originally pro-

pounded because it was thought that electrolysis could be explained in no other way.

In Fig. 7, we have a diagrammatic representation of the condition of the charges in a water molecule when (1) in

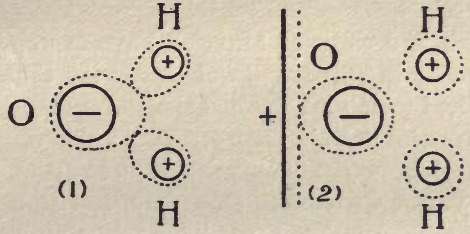

Fig. 7

the interior of the liquid, and when (2) close to the surface of an electrode. In the former position the charges mutually attract each other towards the centre of the molecule. In the latter position, the charge on the oxygen atom is attracted by the positive charge on the electrode, while the hydrogen charges are repelled, and released from their former strain they assume a more normal condition—spherical. It is evident that the attraction of the electrode on the oxygen charge is greater than the resultant in this direction of the attractions of the hydrogen charges. Hence the molecule must be disrupted.

MAXWELL'S THEORY

The name and work of Maxwell have exercised such a great influence in the domain of electricity that it would seem proper, in such a book as this, to touch briefly upon a few main points of his theory. Some idea of his "Electricity and Magnetism" may be formed from the comments of various writers. One describes it as "Pretty stiff reading." Another says, "To ask a student to attempt to assimilate the contents of the two volumes of Maxwell in a year, or even in two years, is only to expose him to the severest pangs of mental indigestion. Again Maxwell's own views are there presented by him with not the greatest clearness, while severe demands are made upon the student's mathematical attainments." Lodge says of it, "Much of it is rough hewn. It contains numerous misprints and errata, and part of the second volume is so difficult as to be almost unintelligible. Some, in fact, consists of notes written for private use, and not prepared for publication." The fact is that some parts of Maxwell's book cannot be understood simply because they are not understandable, and some other parts because they are not so. Thus, while the advice, often lightly given, to "Read Maxwell," can hardly be recommended as affording, even to a mathematician, a profitable return for the time spent, still it is advisable that the student of electricity should have some knowledge of Maxwell's theory, if it can be considered a theory. For Herz said, "Maxwell's theory is simply Maxwell's system of equations."

Nevertheless, we owe to this great man the beginnings of the enormous advances both theoretically and in

practical applications which have transformed our civilization in a generation. Faraday had spent his life in emphasizing the fact that the acting body was not the only thing deserving of attention, but that very important things were also happening in the immediate neighborhood of an electrified or magnetized body. Whence, as was inevitable, a number of later writers have proclaimed that the dielectric played the chief role in all actions, that of the acting body being insignificant. But Faraday never said that, for after all the originating source is "the thing," although not the only thing, as had been thought before.

Maxwell did not discover the ether, but he rediscovered it. He called the attention of mankind to this greatest part of the universe, of which they had previously been sublimely unconscious, and, compared with which, the mass and energy of gross matter is infinitesimal. Only one hundred years before Maxwell, the world had known little more of electricity than Aristotle did. In his time old habits of thinking persisted. The idea of action at a distance without an intervening medium was general, although Newton had clearly recognized the necessity of such a medium. Maxwell shook himself free of all the old fetters, and building where Faraday left off, discovered that all electrical actions were carried by the ether. He also found that light waves instead of being the vibrations pictured in the old undulatory theory, were of a totally different character, and although he failed to recognize clearly and exactly what that character was, yet he showed that they were electro-magnetic phenomena. These two things may be summed up as his chief achievements—and they are enough.

We shall now mention briefly some of the chief points of his theory in detached statements. *"One can imagine that the electro-magnetic strain condition arises through a

*Kalähne. Neuere Forschungen auf dem Gebiet der Electrizität und ihre Anwendungen.

change in the dielectric, which corresponds to a distortion of the particles in an elastic body. Maxwell, following Faraday, describes this change in the dielectric as a dielectric displacement, though this need not necessarily imply an actual displacement of the ether particles." This is quoted to show the vagueness of some of his ideas. Actually, there must be some displacement (motion) of the ether particles. Maxwell's idea seems to be rather that of a strain moving progressively through the medium —an abstract condition—while the medium itself remains at rest.

In every part of a dielectric both kinds of electricity (positive and negative) are supposed to be present in a neutral condition. In the phenomenon of induction, both these electricities previously exist in unlimited quantities in the conductor, and their separation results from a stationary condition of strain set up in the medium. We have seen that the induced charges are applied to the conductor by the waves radiating from the inducing body, and they are held apart by the wave force. According to Maxwell these two kinds of electricity, which are present everywhere, are not only separated in conductors, but also in all dielectrics by a condition of strain. The separation in dielectrics, however, is only through infinitesimal distances, and what he calls the dielectric displacements consists of such separations of the two electricities. The condition of strain which causes these displacements, and the displacements themselves, or the cause and effect, are treated as mathematically equivalent. It is as if a lot of little balls were imbedded in the medium and had their neutral electricity separated into its two components. The displacement takes place successively along such a row of balls in a line of force, by *influence*. Here we have a curious reversion to the old idea of action at a distance. It seems as if the idea of action through a finite distance is repugnant, but this is obviated by strewing a lot of

minute balls throughout space, as, in that case, the action will be only over infinitesimal distances. But to this statement, Kalähne hastens to add that it should rather be taken as a figurative presentation of the case, which need not necessarily be actually so. Whenever we imagine that we have some material platform to stand upon, it is immediately torn down from under us. In a certain sense, Maxwell was right in supposing that the two kinds of electricity exist everywhere in a neutral state, for the neutral ether becomes positive or negative electricity according as it is condensed or rarefied. But Maxwell did not understand it in this sense, since to him the ether was incompressible.

Lines of electric force are merely mathematical representations of observed phenomena, independent of any special suppositions as to the nature of the dielectric displacement. In a condenser which is charged by a current source, while the charge on the plates is increasing and the current is flowing, the lines of force in the dielectric increase. Maxwell considered the increase of the lines of force, or what is equivalent, the dielectric displacement currents, could be regarded as a direct continuation of the current. There was thus, wherever a current was flowing, no such thing as an open circuit. All circuits were closed circuits, and every part of a circuit had its current with its accompanying magnetic field. In the conducting part there was an ordinary current, while in the dielectric there was a displacement current. If we are content to deal with metaphysical abstractions, we may accept this view, but if we have strict regard for the actual facts, it is not so. We have seen that the waves traversing the field in a dielectric, consist of alternating currents in the direction of the lines of force. These, in a certain sense, may be considered displacement currents, but they are not Maxwell's displacement currents, which flowed only one way.

The ether is a dielectric, and Maxwell considered that

displacement currents occur in the ether, as in all dielectrics. He thought that each displacement current should have its own magnetic field, just as current in a conductor is surrounded by a magnetic field. As a matter of fact currents in the free ether, such as the to and fro currents of a longitudinal wave, or the hypothetical displacement currents of Maxwell, do not have any magnetic field. The magnetic field accompanying a current in a conductor is formed by the resistance opposed to the current by the atomic surfaces.

Assuming displacement currents in the ether and that they are accompanied by magnetic fields, it is possible to form equations which express the time relation of the variations of the electric force (which we can consider indifferently a line of electric force or a displacement current) to its magnetic field, or to the space distribution of the magnetic strain condition. This gives us one set of Maxwell's equations for electro-magnetic disturbances in space.

Then he considered that the variation of the magnetic force should likewise cause variations in the electric field, or displacement currents. The next step was to suppose that the magnetic forces and the electric forces possessed, what are known in mathematics, as conjugate properties. That is, the expressions for the variations of the one quantity in terms of the other, can conversely give the variations of the other in terms of the first, by simply interchanging the symbols of the one for the other.

There was now a difficulty. One set of equations—those for the electric forces—had an expression for a displacement current. There could be no such thing as a magnetic displacement current, or a magnetic current of any kind. So the corresponding expression was simply left out. Thus Maxwell's two sets of equations were derived—one set for the electrical forces, the other set for the magnetic forces.

The mechanism by which the propagation of these

electro-magnetic waves is accomplished is left "in the air." There are not necessarily any actual physical vibrations, or any motion even, although their possibility is not necessarily excluded. The process is simply a periodic and progressive rise and fall of electric and magnetic forces from point to point in space. Certain hypothetical forces, which are pure abstractions, are dealt with in certain equations, and a result is obtained. It is shown that both the magnetic and electric forces lie in the plane of the wave and are perpendicular to each other. Of course electric and magnetic forces, mutually interdependent, must be perpendicular to each other.

If we should begin to make some mental image as to the nature of these disturbances, we should be told that we must not think of anything tangible, not even of motion, but merely of a passing rise and fall of energy at some point, and that the electric and magnetic forces were perpendicular to each other.

Now we have seen that an electro-magnetic wave consists of a spreading out of vortex tubes. The electric force, or the current sheet, which corresponds to what Maxwell calls the displacement current, is circular and has all directions. One of these directions is, of course, in the plane of the wave, and the direction of the magnetic force, or axis of the tube, is in the plane of the wave. Now it happens that the only motion of the current sheet which can possibly be detected by the eye, or in any other way, is the one in the plane of the wave, since the effects of the motions in all other directions are self-eliminatory. This motion and the magnetic line lie in the plane of the wave, and they are perpendicular to each other. So far we have a corroboration of Maxwell's theory as to the position and direction of the forces. It follows that a vortex tube is a practical realization of Maxwell's abstract reasoning, as far as that is possible, and it is fairly evident that there can be no other motion which is such a realization.

MISCELLANEOUS

We have hitherto stood upon tolerably firm ground. We can assume with a fair degree of confidence that the ether and electricity are synonomous. A positive charge of electricity is a condensed mass of ether. A negative charge of electricity is a rarefied portion of ether. Attraction and repulsion generally are due to longitudinal waves, the action depending upon the kind of the wave (there being two kinds), and upon whether the body is denser or less dense than the medium. This action is not confined to the ether, but is seen in all media. Thus two tuning forks emitting longitudinal waves attract each other. A tuning fork attracts a balloon filled with carbonic dioxide, while it repels one filled with hydrogen. The radiations from the surface of a carbonic dioxide balloon repel a similar balloon, while attracting a hydrogen balloon. A hydrogen balloon repels a similar balloon while attracting a positive balloon. Gross matter and negative charges of electricity radiate positive waves; positive charges of electricity radiate negative waves. Magnetic lines are linear vortices in the ether, and electro-magnetic waves consist of trains of such vortices travelling outward with the normal velocity of the medium. Chemical affinity is the attraction of equal and opposite charges on the atoms or radicles of a molecule.

There are, however, many phenomena outstanding which must continue to be the subject of speculation. That light rays should continue in a straight line, as sound waves do not, is easily intelligible from their vortex structure. The great difficulty with the old undulatory

theory was how to account for polarized rays. Knowing that such rays consist of trains of vortex tubes, the difficulty is reversed, and it might seem that all rays should be polarized. It is evident, however, that the promiscuous positions of these tubes in ordinary light is because the vibrations are continually shifting in direction. That they should be deflected slightly from a straight course on grazing a sharp edge, we should expect, since the grazing side of a vortex will be slightly retarded or accelerated according to the direction of its rotation, with the result that the vortex will be deflected above or below the edge. That the *diffraction bands* should be wider and extend to a greater distance above the edge than below, we likewise could have predicted.

We have seen that the rate of the outflow of energy from a body at a higher potential than its surroundings is proportional to the excess of its potential, when the energy streams out in the form of longitudinal waves. This is not the case when the energy is radiated in the form of electro-magnetic waves. The number of vortices generated in a conductor in a given time is proportional to the current and also to the suddenness with which the current rises, or it is proportional to $\int_0^t C\frac{dC}{dt}$. Hence the number of vortices generated in unit time should be proportional to the square of the current. Now the magnetic energy in a vortex we have seen to be measured by the square of the velocity of the current sheet. This current sheet has the same velocity as the generating current at the instant that it leaves the wire, and a current is measured by its velocity. Hence the total output of energy in unit time should be proportional to the fourth power of the current, and since the current is proportional to the pressure, it should also be proportional to the fourth power of the potential. Stefan's formula states that the electro-mag-

netic radiation (heat) of the sun is proportional to the fourth power of its temperature or potential. Since the surroundings of the sun into which this radiation takes place are at the absolute zero, or the temperature of space, the potential must be measured from the absolute zero. Stefan's formula is $\frac{E}{t} = \tau^4$, or the amount of heat radiated per unit surface of the sun per unit time is measured by the fourth power of its absolute surface temperature. It is more than a formula and can be considered as expressing a law. The amount of energy radiated by a wire, in wireless telegraphy, in unit time, should be proportional to the fourth power of the average pressure in the wire. This law has not as yet been examined in connection with radio-telegraphy, but it would doubtless find confirmation.

When an atom vibrates, or moves to and fro along a line, it generates both electro-magnetic waves and longitudinal waves. The edges of the condensed ether in front curl round over the rarefied ether behind and thus a vortex is formed, while from the central part the longitudinal wave is started. Thus, with every excursion in one direction the compressed half of a longitudinal wave is formed as well as a vortex rotating in a definite direction, while, with the return excursion, the expanded half of the longitudinal wave is completed and another vortex rotating in the opposite direction is formed. The direction of the alternating currents in the longitudinal wave is the direction of the vibratory motion, while the vortex rings spread out in a plane perpendicular to this direction. The electric forces (the currents) are perpendicular to the magnetic forces (the vortex filaments), as is inevitable. The two kinds of energy radiated are not equal, for while we may suppose the longitudinal wave energy to remain measurably constant, the electro-magnetic energy radiated

increases as the fourth power of the pressure, and this varies as the frequency of the vibrations. Hence it would seem probable that the attraction exerted by a body is not influenced by its temperature, while the electro-magnetic radiation varies as the fourth power of the temperature.

If we seal electrodes into a bulb from which a gas has been partially exhausted, we can transfer electricity through it. The transference is by convection, as in the case of an electrolyte. The molecules of the gas receive charges and are violently repelled. They become dissociated into their atoms, either from the charges they receive or from the violent impacts on the electrodes. When the source of energy is, as usual, an inductorium, the field is very strong and practically constant, the lines of force extending from the anode to the cathode.

Certain bodies called *electrons* are produced, the nature of which is not yet fully determined. They are certainly not atoms of electricity, for electricity is the ether, and the ether as far as we know is a continuum. If they were ether atoms, they would not be differentiated from the rest of the ether, and therefore could not be observed. They may possibly be minute vortex rings—rings without any central lumen—which are given off from the electrodes as the current surges violently and brings up with an impact on the end surfaces. We have seen that a rising current in a wire is full of such vortices which are shoved outward around the wire. From an end surface they may be simply projected away normally to the surface.

Such vortices are very much less dense than the ether. Consequently they constitute a negative charge, and may be considered to be mainly a negative charge with practically no mass. In an electric field they are urged towards the positive electrode with the standard velocity; in a magnetic field with its lines perpendicular to their line of flight, they are deflected in the same direction as a

wire would be carrying a current from the anode to the cathode. They should traverse the space from the cathode to the anode with the standard velocity, and with proper conditions they very nearly attain this velocity. Where there are too many atoms and molecules of the gas in their path, their progress is impeded, and their velocity may fall to two-thirds of the standard velocity, or even lower.

When electrons strike upon a resisting surface they give rise to what are known as X rays. It is possible that they are burst by the violent impact and cease holding their vacua. They thus become dissipated into the general ether and cease being a differentiated part of it. Their energy, which is magnetic, becomes transformed into a violent explosive ether wave, just as when a vacuum bulb is dashed against an object an explosive air wave results. As in air such a violent single unidirectional wave may travel with many times the standard velocity, so these explosive waves, or X rays, may move with a velocity which is limited only by the energy expended and the suddenness with which it is expended. But we are here in the realm of speculation.